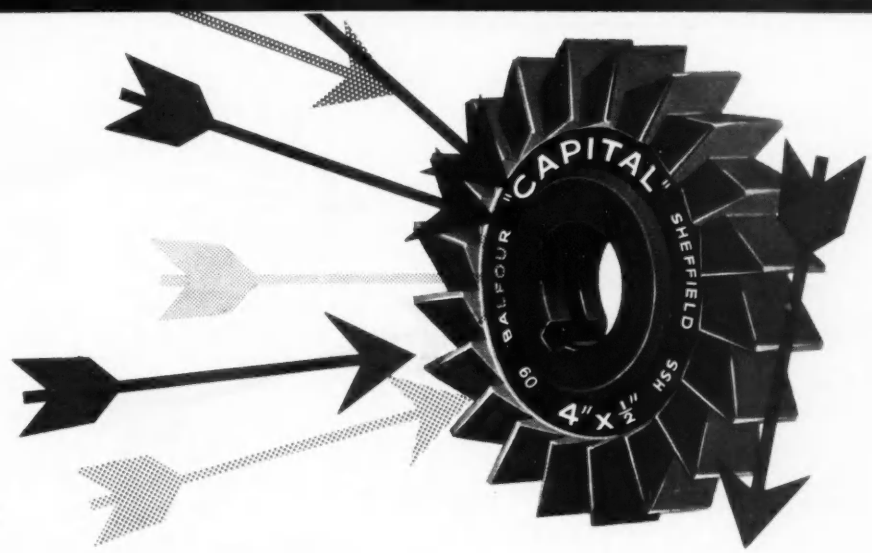
The
ENGINEERS' DIGEST

A World Review of
DESIGN & PRODUCTION · RESEARCH & DEVELOPMENT

VOL. XXII No. 11 NOVEMBER, 1961



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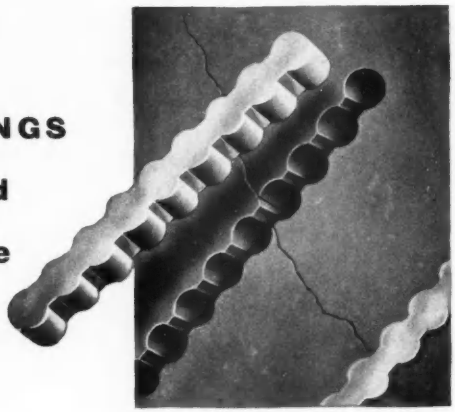

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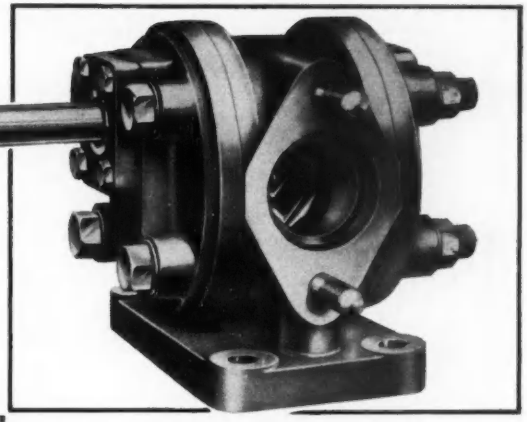

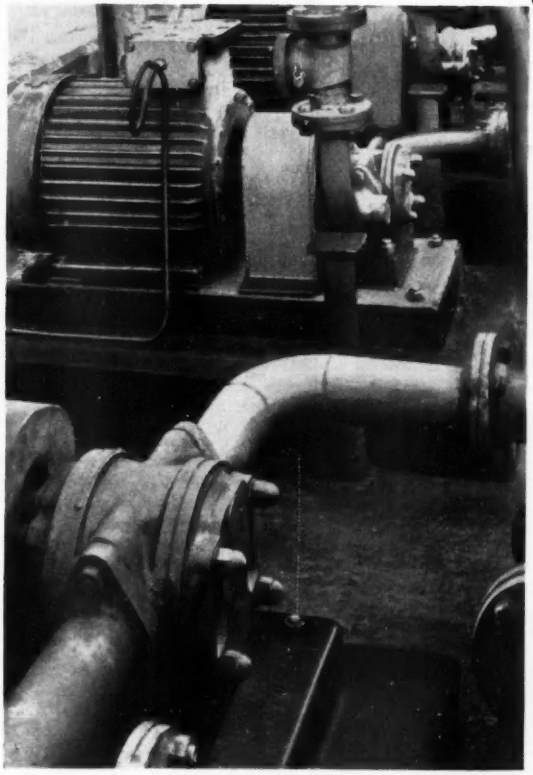

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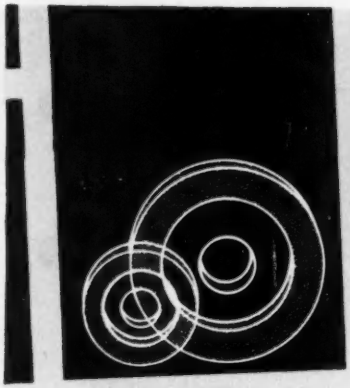

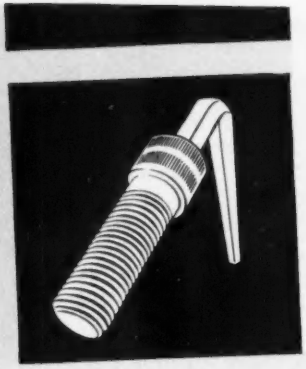

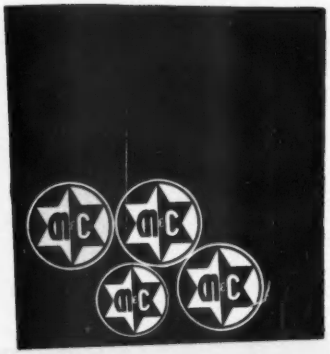

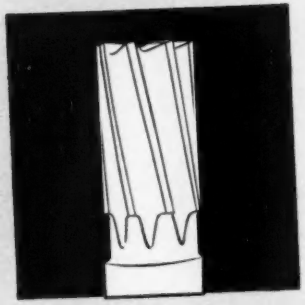

Engineers'

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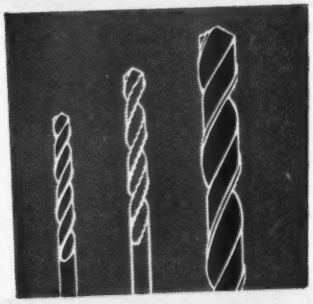

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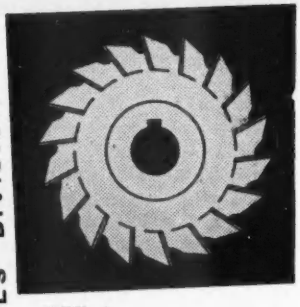

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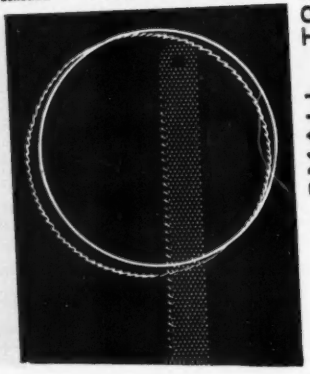

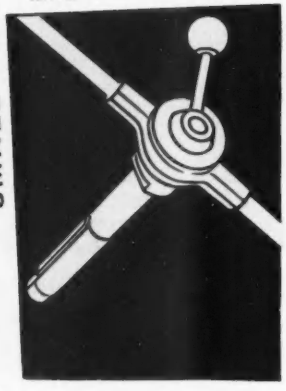

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CONTENTS

	Page
The Minidigest	4
Business Notes	8
Contracts	12
Personal	14
News Round-up	16
Latest Industrial Literature	20
The Blue Pages	73
Electrical and Metallurgical Factors Affecting Welding-Arc Stability	81
Tests on Cross-Flow Heat Exchangers with Tubes of Different Shapes	83
The Determination of Losses in Electrical Machines by Calorimetric Methods	87
Transformer Bank with a Rating of 1000 MVA	88
The Theory of Combined Steam- and Gas-Turbine Installations (*concluded*)	90
Stratified-Charge Systems for Spark-Ignition Engines	93
The Machining of Difficult-to-Deform Metals	97
British Industrial Developments	115
New Materials, Processes, and Equipment	121
Index of Advertisers	157

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FROM ALL BOOKSELLERS

The

MINIDIGEST

Making it possible to produce isoprene at a competitive cost, a **new synthetic-rubber process** has been developed in the U.S.A. by the Goodyear Company and the Scientific Design Company. In this process, two molecules of propylene, a by-product of petroleum cracking, are combined to form a six-carbon-atom molecule called methylpentene, from which a carbon atom is then knocked off to give the five-carbon-atom molecule isoprene.

* * *

A new colorimetric method for the determination of copper in boiler feed water has been developed by the Hitachi Research Laboratory and is reported in the *Journal of the Chemical Society of Japan* for April 1961. The method utilizes diphenylcarbohydrazide to give an extremely sensitive colour reaction to copper in basic solutions, the optimum temperature of the samples tested being 30°C and the time required for colour development only 10 min. Interference occurs only when, in addition to copper, considerable amounts of iron, zinc, and chromium are present in the water, though their effects can be overcome by the addition of a citrate to the sample.

* * *

Designated reduced-oxide coating, a **new method of producing metallic coatings,** developed at the Armour Research Foundation, involves spraying the metal surface with a metal oxide and then reducing with hydrogen. The application of the oxide is effected by a flame-ceramics process perfected at the Foundation. Studies of reduced-oxide coatings utilizing nickel oxide have shown that the layer of nickel adjacent to a steel base is converted to dense, continuous, and pore-free metal. The outer region of the coating displays some porosity, but is free from long continuous cracks. It is stated that the technique should apply to any oxides which can be reduced easily, including those of copper, nickel, tungsten, iron, molybdenum, and their alloys.

* * *

A technique of **avoiding distortion of steel plate by cutting under water** has been devised in England by the Consett Iron Co. Ltd. to simplify the fabrication of 1500 steel convector plates required by a customer. In this technique, the plate, $\frac{3}{16}$ in. in thickness, was covered in a special trough by a $\frac{1}{4}$-in. layer of water during

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HAND TOOL DIVISION OF THE BREN MANUFACTURING COMPANY

The MINIDIGEST

cutting with an oxygen cutting machine. In this way, all heat was quickly dispersed, and the normal distortion obtained with this thickness of material was prevented. Owing to the presence of the water, the cutting speed was about half that normally obtained with this plate thickness, each plate being profiled in about 45 min. However, this additional cutting time is considered a minor drawback, compared with the results which can be achieved in eliminating distortion.

* * *

Control of the grain size of steels can be obtained by the addition of various elements, the most widely used being aluminium. It is now reported that, following an investigation by the British Iron and Steel Research Association to determine the percentages of aluminium giving the most effective grain control and the optimum method of addition, a supplementary conclusion of special interest is that measurement of the aluminium content constitutes a **simple method of evaluating the grain size of steel** and is a reliable, rapid, and less expensive alternative to the universally accepted McQuaid-Ehn test for the quantitative determination of grain size. The McQuaid-Ehn test has the disadvantage that a temperature of 925°C is required for testing and therefore imposes unduly strict conditions for specifying grain-size requirements where steels for normal engineering and heat-treating applications below this temperature are concerned. Measurement of aluminium content as a guide to grain size eliminates this disadvantage and can easily be carried out by spectrographic analytical equipment, which, in any case, is already being installed in many steelworks.

* * *

It is reported in the Austrian journal, *Radex Rundschau* (No. 4, 1961), that a **new precision-forging method for turbine blades** has been developed by Gebr. Böhler & Co. A.G., of Kapfenberg. It is stated that the method used provides a continuous grain flow from end to end of the turbine blades and that such close tolerances and excellent surface finish are obtained that only final polishing is required. The process is inherently economical, but greater economy is naturally obtained if the components are of complex shape and if high-alloy steels which are difficult to machine are used.

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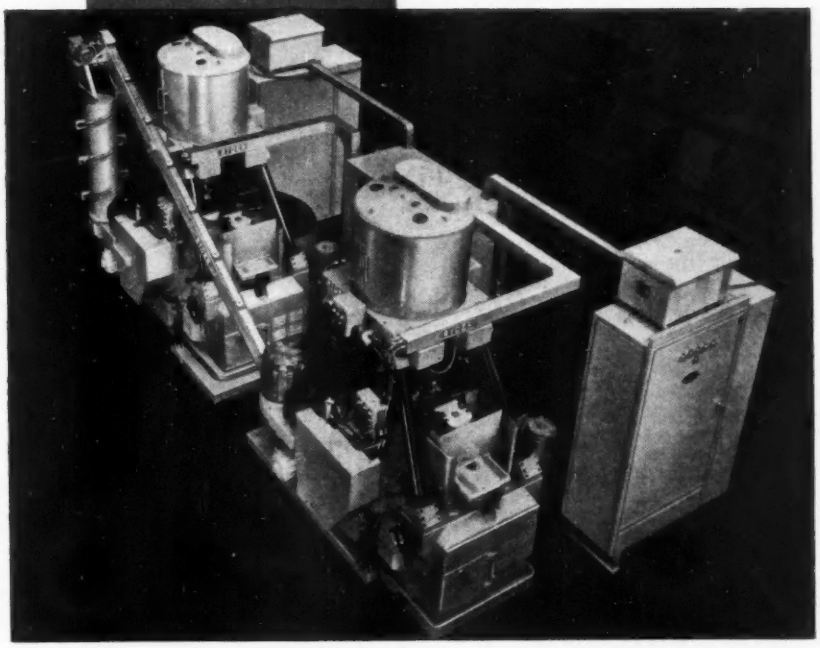

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See *Ryder* **about automatics and auto-handling**

BUSINESS NOTES

An agreement has been signed between **Research and Control Instruments Ltd.**, of London, W.C.1, and **Sonatest Ltd.**, also of London, W.C.1, enabling marketing in the U.K. of Sonatest ultrasonic non-destructive testing equipment to be carried out exclusively by Research and Control Instruments Ltd., whose scope is now extended to cover a wide range of applications for non-destructive testing.

* * *

Sulphamic acid is now being supplied by **Albright & Wilson (Mfg) Ltd.**, of London, S.W.1, from the first plant in the U.K. to produce this acid in bulk. The acid is manufactured by **Marchon Products Ltd.**, another company in the **Albright & Wilson International Chemical Group**, in a new plant at Whitehaven in Cumberland. This plant has been designed and built by Marchon themselves, and uses sulphur trioxide from their anhydrite kilns on the same site for the production of the sulphamic acid. As the only crystalline strong acid in existence, sulphamic acid has many advantages over liquid acids, but retains all the essential properties. Its most important advantages include the ease with which it can be transported and stored, the absence of vapour, even when heated, and safety in handling. It is especially valuable in dyeing processes in the textile and leather industries and as a universal cleaner and descaler of metals.

* * *

A new company, **Hardie-Ferodo Pty. Ltd.**, will shortly be formed in Australia with an authorized capital of £A3,000,000 for the manufacture and marketing of brake linings, clutch facings, and other friction materials for the automotive and general industrial field. The new company is being created by a merger of the Australian Ferodo interests of **Turner & Newall Ltd.**, of Manchester, and of the brake-lining division of **James Hardie & Co. Pty. Ltd.**, of Sydney, makers of "Hardibestos" linings. Turner & Newall Ltd. will have a substantial minority holding in the new company, which will be operated by **James Hardie Asbestos Ltd.** as a subsidiary.

* * *

As a result of a recent sales agreement between **The Wayne Kerr Laboratories Ltd.** and **Gertsch Products, Inc.**, Wayne Kerr now hold the sole U.K. marketing and manufacturing rights for Gertsch precision electronic instruments. Sales and service enquiries regarding these American products should be addressed to Wayne Kerr at 44 Coombe Road, New Malden, Surrey (Tel: MALden 2202).

* * *

Bearing in mind the increasing interest of the machine-tool industry in electronic control, **Compagnie Européenne d'Automatisme Electronique (CAE)**, of Paris, who have hitherto specialized in the application of computers to the operation of large industrial plant, have decided to add to their programme of computers and processors a series of systems for the control of machine tools. For this reason, an agreement has been signed between CAE and **Thompson Ramo Wooldridge**, with a view to the sale and

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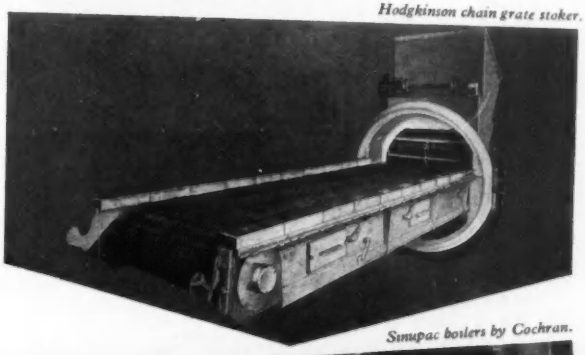
A view of Whitrigg Colliery.

...will be fed...

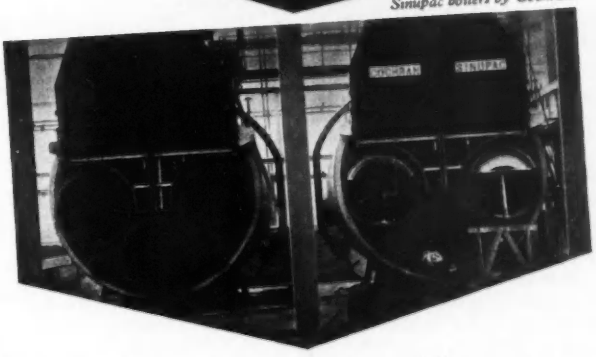
Hodgkinson new design Mark V chain grate stokers are being installed by B.M.C. for maximum thermal efficiency. These stokers maintain a flexible heat control, burn coal smokelessly and can cope rapidly with fluctuating loads.



Hodgkinson chain grate stoker.

...into these...

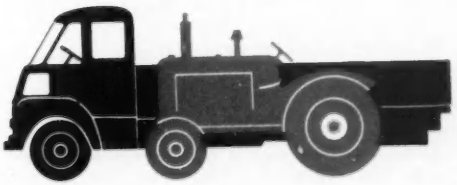
Five high pressure automatically controlled, hot water Cochran 'Sinupac' boilers will each burn (per hour) 1.8 tons of untreated smalls containing 40 per cent. fines. B.M.C. choose Cochran because, even with this low-grade coal, the efficiency will be approximately 80 per cent. on the gross C.V. The total capacity of the five boilers is potentially 160,000,000 B.T.U.'s per hour. This will increase when the factory is in full production.



Sinupac boilers by Cochran.

to power the factory that makes these...

The new B.M.C. factory—an important landmark in the industrial progress of Scotland—will produce approximately 400 tractors and 1,000 commercial vehicles a week, and will employ some 5,000 to 6,000 people. This new B.M.C. factory burning British coal automatically fired by Hodgkinson stokers in Cochran boilers, will increase Britain's prosperity at home —and British trade overseas.



BMC DRIVE AHEAD WITH COAL, HODGKINSON AND COCHRAN

BUSINESS NOTES

production in Europe of systems developed by the electro-mechanical department of the latter company in Michigan City, Indiana. CAE is a joint venture of **Compagnie Générale de Télégraphie sans Fil (CSF), Thompson Ramo Wooldridge,** and **Intertechnique,** and is in charge of producing industrial control systems based on computers for the Common Market.

* * *

"Bascodur", an anti-corrosive protective lining for plug valves, globe valves, angle valves, low-pressure gate valves, and sight flow glasses, is now available for the first time in the U.K. through the British agents, **I. V. Pressure Controllers Ltd.,** of 683 London Road, Isleworth, Middlesex, who have the sole rights to this product. Bascodur-lined valves are manufactured in Germany at **Eisenwerk Rödinghausen,** Lendringsen, Krs. Iserlohn.

* * *

Varatio-Strateline Gears Ltd., of Trading Estate, Slough, have now moved into a new and larger factory at Follsain Works, Ajax Avenue, Trading Estate, Slough, Bucks. (Tel: Slough 26655; telegrams: Varatio, Slough).

* * *

Imperial Chemical Industries Ltd., of London, S.W.1, **Magneto-Chemie N.V.,** of Schiedam, Holland, and **The Amalgamated Curaçao Patents Co.,** of Curaçao, have agreed to pool their appropriate patents and to collaborate in the development and extension of the use of titanium anodes coated with an extremely thin film of platinum or similar metals. These coated anodes offer considerable advantages over conventional materials in industrial electrolytic cells for chemical manufacture, electroplating plant, and equipment for converting brine to drinking water. They are also used for the cathodic protection of ships and structures against seawater corrosion, but their greatest field is undoubtedly in the production of chlorine by the electrolysis of brine, and numerous large-scale chlorine producers are evaluating them for this application, including the General Chemicals Division of I.C.I. The Metals Division of I.C.I. are marketing platinized titanium anodes manufactured in the U.K. by their subsidiary company, **Marston Excelsior Ltd.,** of Wolverhampton.

* * *

The **Insley Industrial Supply Co. Ltd.,** distributors of precision balls, bearings, and machine-tool accessories, have now changed their name to **Insley Industrial Ltd.** and have moved to new and larger premises at 5 Windmill Street, London, W.1. (Tel: LANgham 5426-8).

* * *

A new British company, the **Consolidated Electrodynamics Corporation (U.K.) Ltd.** has been set up to complement the activities of the **Consolidated Electrodynamics Corporation, Inc.,** of Pasadena, Cal. The new company is a wholly owned subsidiary of **Bell & Howell, S.A.,** of Fribourg, Switzerland, which is in turn owned by the **Bell & Howell Company,** of Chicago, Ill. The Consolidated Electrodynamics Corporation, Inc. is wholly owned by the Bell & Howell Company and itself owns the **Consolidated Electrodynamics Corporation, G.m.b.H.,** of Frankfurt, Germany. It is stated that the new British company will be much more than an offshoot manufacturing for the home market, as it is intended to be one of the most important manufacturing centres for export for the C.E.C. organization. The headquarters of the Consolidated Electrodynamics Corporation (U.K.) Ltd. is at 14 Commercial Road, Woking, Surrey (Tel: Woking 5633, Telex No. 8-582).

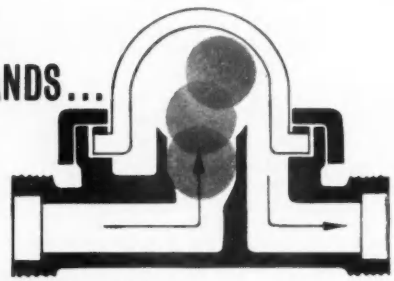
* * *

It is announced by **Allen West & Co. Ltd.,** of Brighton, manufacturers of electric-motor control gear, that they have acquired a 56,000-sq ft factory at Newtownards, Co. Down, Northern Ireland. The factory, which was formerly occupied by Lee Guinness, Ltd. and is Government-built, has ample room for expansion, and will immediately be used for the assembly and wiring of standard Allen West contactor panels.

* * *

Following a recent agreement with **Yuba Consolidated Industries, Inc.,** of Tulsa, Oklahoma, **Birwelco Ltd.,** of Aston, Birmingham, a wholly owned subsidiary of the **G.K.N. Group,** will manufacture Aimco "Transaire" air-cooled heat exchangers for sale in Europe and the British Commonwealth. These exchangers incorporate finned tubes and electrically driven fans, and are designed specifically for the oil-refining, petrochemical, and chemical-processing industries. They are particularly useful where the water supply is inadequate or unreliable.

LOOK NO GLANDS...



... no stuffing box either —in fact nothing to wear out at all!

This is the SHOFLO, the sight flow indicator that shows you whether or not liquid is flowing in a pipeline *even above eye level.* Simple and positive in operation, the SHOFLO prevents reverse flow, is ruggedly built with a toughened glass dome and easily withstands pressures of up to 100 p.s.i. Available in three sizes of ¼", 1" and 1½" bores, male or female connections—the ¼" size can be supplied with right angle inlet and outlet.
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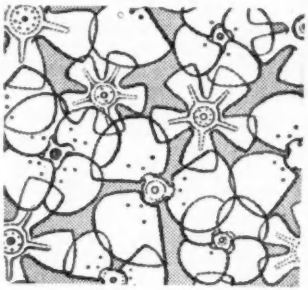
PCM17b

PROPELLER FANS?
YES, SIR!
BIGGEST RANGE IN THE COUNTRY



SMITHS TORRINGTON propeller fans, the widest range existing in this country, are promptly available from stock – 3" to 24" dia., either rotation, in a variety of pitches.

AIROTORS?
YES, SIR!
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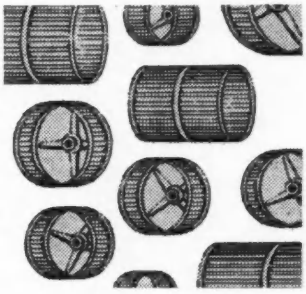
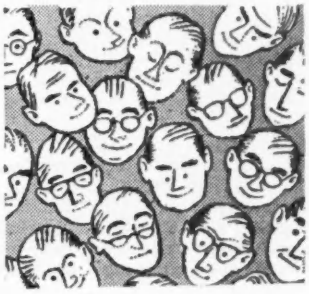


SMITHS TORRINGTON wide range of airotors are also promptly available from stock in following sizes – 1½" to 11" dia., widths from ¾" to 11", in steel or aluminium.

BOFFINS?
YES, SIR!
BIGGEST BRAINS IN THE COUNTRY



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AND NOW—FOR STILL GREATER ECONOMY— STANDARDISED BLOWER CASES

COMPLETE BLOWER UNITS, AND SPECIALITY BLOWER UNITS TO YOUR SPECIFICATION

Standardised sheet metal blower cases are now available to fit all sizes of SMITHS TORRINGTON airotors, both single and double inlet. This range offers the maximum versatility: piercings can be provided for a variety of motor mountings; special finishes can be provided as well as the standard Hammer Blue/Green; individual performance curves supplied on request; speciality blowers can be designed and manufactured to your special performance requirements.

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CONTRACTS

Orders for Efco furnaces to a value of approximately £70,000 have recently been obtained by Efco (Sth. Africa) (Pty.) Ltd. The orders cover an electrically heated closed-quench furnace, a pit-type gas carburizing furnace, a continuous mesh-belt conveyor furnace, and two bogie hearth furnaces, each rated at 750 kW. The bogie hearth furnaces are to be supplied to South African Railways for normalizing, annealing, and stress-relieving steel castings and will take loads up to 8 tons.

* * *

It is announced by The Bronx Engineering Co. Ltd., of Lye, Stourbridge, that they have received export orders totalling about £90,000 during recent weeks. Of these, Stankoimport, Russia, has placed a £45,000 order for plate-bending rolls, while a £24,000 order has been received from Finland for two large tube-straightening machines for copper tube. In addition, orders worth £14,000 for tube-straightening machines have been received from Czechoslovakia, and a similar order, valued at £7,000, has been received from Switzerland.

* * *

Orders totalling £250,000 have been received by Honeywell Controls Ltd., of Greenford, Middlesex, for process-control instrumentation in connection with the new integrated Spencer steelworks of Richard Thomas & Baldwins Ltd., near Newport, Mon. Temperature, flow, pressure, and oxygen-analysing equipment will be supplied for the reheating and heat-treatment furnaces being installed by Priest Furnaces Ltd., Stein and Atkinson Ltd., and the Incandescent Heat Co. Ltd. In addition, instrumentation is being installed for lime kilns, ore dryers, pickle lines, and acid-recovery and other plant, mainly on direct order from Richard Thomas & Baldwins. Most of the instrumentation will be made in Scotland, and a considerable part of the installation will be carried out by Honeywell Controls themselves.

* * *

The Power-Gas Corporation Ltd., of Stockton-on-Tees, a member of the Davy-Ashmore Group, have been appointed main contractors by Magnesium Elektron Ltd. for the engineering of a new plant at Hopton, Derbyshire, for the production of 5000 tons per year of magnesium. The plant, which will make the U.K. largely independent of imports from overseas, will extract magnesium of 99·9% purity from local dolomite by a reduction process which has not previously been operated on a commercial scale in this country. The total value of the completed plant to Magnesium Elektron is expected to be in the region of £2,000,000.

* * *

An order, valued at about £125,000, has been received by The General Electric Co. Ltd. from the Reed Paper Group for a 5-MW pass-out geared turbo-generator and the associated condensing plant, to be installed alongside two existing G.E.C. sets in the Empire Paper Mills of the Group at Greenhithe, Kent. Designed for inlet-steam conditions of 600 psig and 800°F, the turbine will exhaust to a vacuum of 28·5 in. Hg and will be fitted with a pressure-controlled pass-out for the delivery of up to 80,000 lb/hr of process steam at 20 psig. The condensing plant will be manufactured by Hick Hargreaves & Co. Ltd.

The General Electric Co. Ltd. has also received an order, valued at £70,000, for blending machines to be installed in Belgium in the Athus steelworks of S. A. Cockerill-Ougree. The equipment is to be incorporated in an ore-blending plant and comprises a reclaiming machine, a transfer car, and a double-hinged boom stacker. The reclaiming machine will have a capacity of from 380 to 500 tons/hr, depending on the density of the ores concerned, while the stacker will be fitted with belt conveyors of 43 in. width and will be capable of stacking at a rate of 800 tons/hr.

* * *

A contract has been received from the General Post Office by the Brush Electrical Engineering Co. for the supply of control equipment, motors, generators, and servo-equipment for a steerable aerial now under construction at the Goonhilly Downs Post Office Radio Station in Cornwall. Another Hawker Siddeley company concerned in the project is Whitworth Gloster Aircraft, whose Electronics Division is building some of the digital electronic equipment. The paraboloid aerial, 85 ft in diameter, is similar in principle to the Jodrell Bank radio telescope, for which Brush were also responsible for supplying the motive-power equipment, and will be used for tracking radio-communication satellites in a joint G.P.O. and American experimental programme scheduled to take place next year. In this programme, American satellites will be used to transmit speech, telegraphy, and television across the Atlantic.

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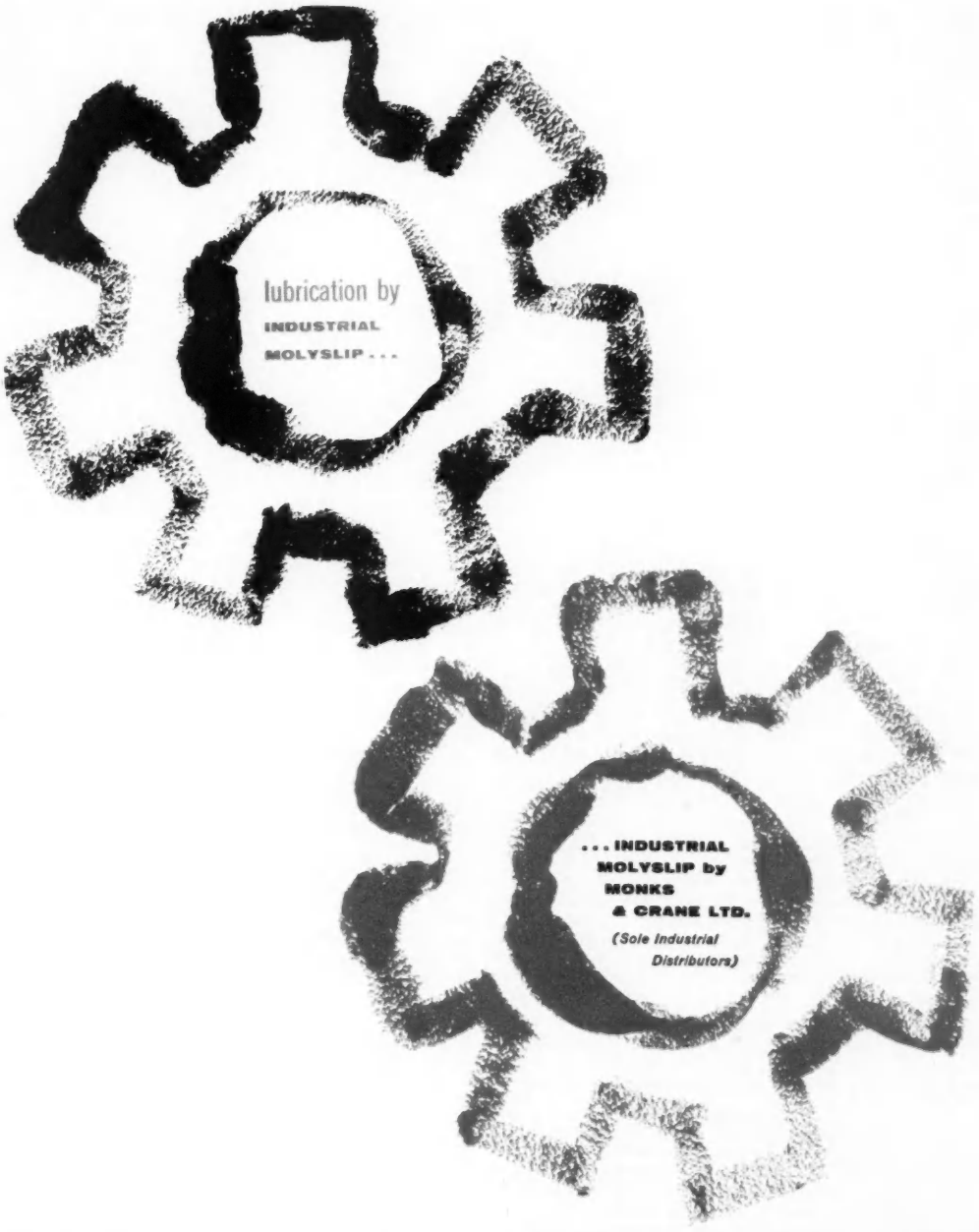

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PERSONAL

It is announced by The Hairlok Co. Ltd., of Bedford and London, that **Mr. E. A. Falkner** has been appointed to the board of Hairlok Laboratories Ltd., of Chiswick, London, who are the design, development, research, and testing division of The Hairlok Co. Ltd.

* * *

Mr. H. Smith, chairman and joint managing director of British Ropes Ltd., of Doncaster, has joined the board of The United Steel Companies Ltd., of Sheffield 10.

* * *

It is announced by Head Wrightson & Co. Ltd. that **Mr. J. D. Eccles** has been appointed director and general manager of Head Wrightson Stockton Ltd. **Mr. G. F. Taylor** has been appointed general manager of Head Wrightson Steel Foundries Ltd., while **Mr. A. J. Long** has joined the Head Wrightson Export Company as general manager.

* * *

Mr. R. Butler, previously a director of Quasi-Arc Ltd., has been appointed managing director of the Eutectic Welding Alloys Co. Ltd., a member of the Eutectic/Castolin International Group.

* * *

The Plessey Co. Ltd. announce the appointment of **Brigadier J. D. Haigh, O.B.E., M.A., M.I.E.E.,** one of Britain's early radar experts, as general divisional manager of a group of divisions which include the wiring and connectors division, the capacitors and resistors division, and Preformations Ltd.

* * *

Mr. R. P. E. Tabb has been appointed deputy director of engineering of The English Electric Co. Ltd. This directorate is responsible for the engineering policy of the whole range of the company's products (other than those of English Electric Aviation), and Mr. Tabb will mainly be concerned with the company's technical development programmes.

* * *

It is announced by Drummond-Asquith Ltd., of Birmingham, that **Mr. R. Quigley,** who has been area manager of their Scottish territory for many years, has been appointed home sales manager of their organization.

* * *

Mr. J. A. W. Gill has been appointed a director of Steele & Cowlishaw Ltd., of Hanley, Stoke-on-Trent. He will retain his position as manager of the chemical-machinery sales department of Baker Perkins Ltd., of Peterborough, the parent company of Steele & Cowlishaw Ltd.

* * *

Mr. J. W. Warner, M.A., M.I.Mech.E., A.M.I.E.E., has been appointed to the board of Alkaline Batteries Ltd., of Redditch, Worcs.

It is announced by AMF Ltd., a member of the American Machine & Foundry Co. International Group, that **Mr. D. A. Bell, B.A., Ph.D.,** has been appointed director of their new research laboratory at Blounts Court, Peppard, near Henley-on-Thames.

* * *

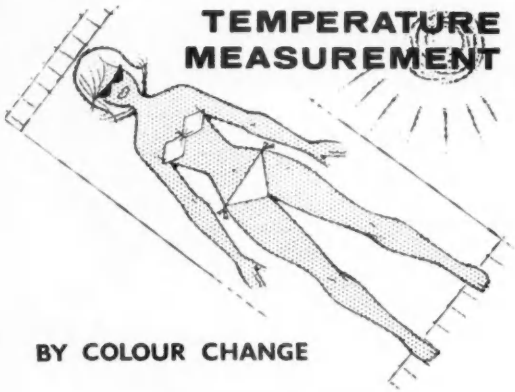
Churchill Gear Machines Ltd., of Blaydon-on-Tyne, announce that **Mr. C. R. Tearne,** formerly technica sales manager, has been appointed director of the company. **Mr. W. Guss** has now been appointed technical sales manager, while **Mr. T. Lewins** becomes chief machine-tool designer, and **Mr. P. Wedgwood** chief engineer.

* * *

Sir Ben Lockspeiser has been appointed to the board of Cyril Adams & Co. Ltd., one of the machine-tool companies in the Staveley Group. Sir Ben is scientific adviser to the Group and is on the board of Staveley Industries Ltd., the parent company. Staveley also announce that **Mr. F. Menelaus** has been appointed a director of Wilkinsons Tools Ltd., of Warrington, another member of the Staveley Group, moving from yet another Staveley company, George Richards & Co. Ltd., of Broadheath, where he was development engineer.

* * *

The Griffin & George Group of companies announce that **Mr. D. S. Beard, Ph.D., A.Inst.P., A.R.C.S., B.Sc.,** has been appointed to the board of Griffin & George (Sales) Ltd. in the capacity of technical sales director.



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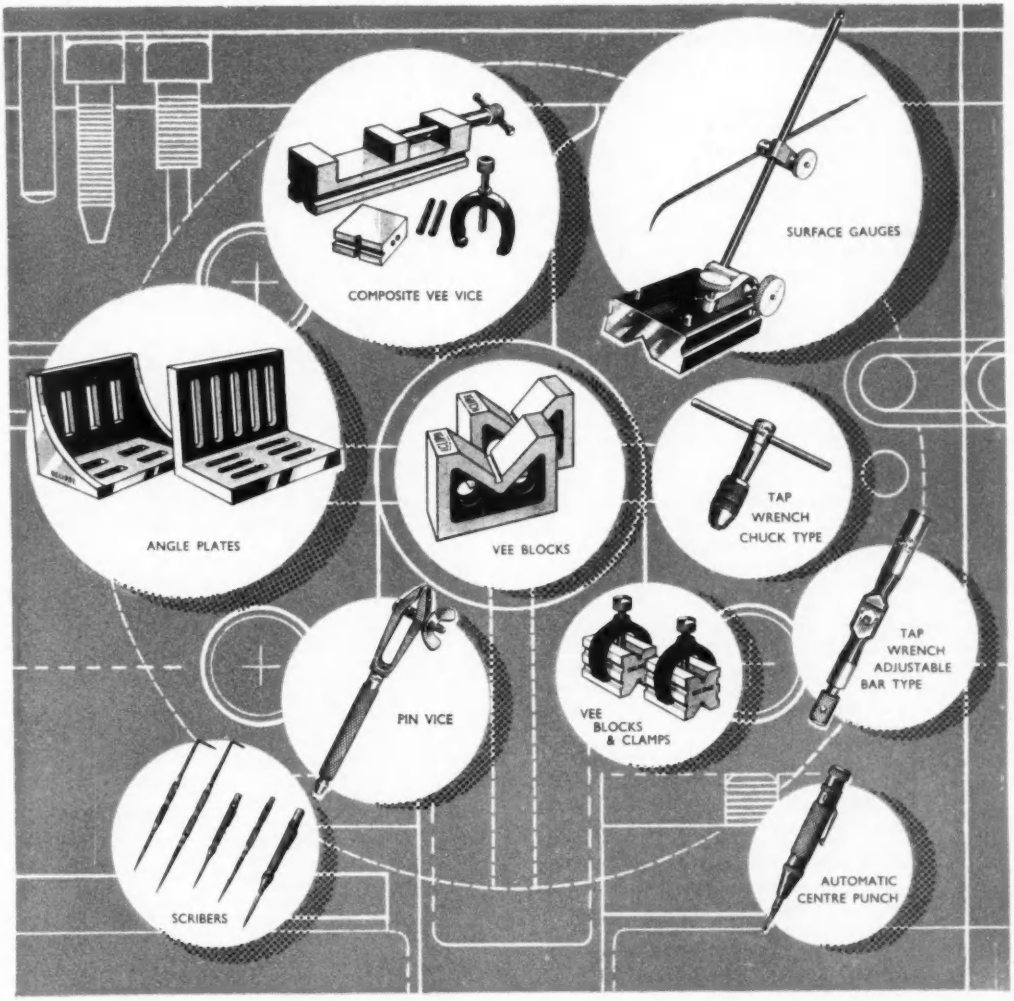


work to fine limits

with Eclipse

'Eclipse' hacksaw blades and other tools are made by James Neill & Co. (Sheffield) Ltd. and are obtainable from all tool distributors.

UXE2

NEWS ROUND-UP

New Factory for Royce Electric Furnaces

Occupying a prominent corner position in the L.C.C. Industrial Development Area at Sheerwater, near Woking, Surrey, a new factory has been constructed by Royce Electric Furnaces Ltd. The sales and design staff, together with administration staff, are housed in a new office block in front of the factory. The products of the factory range from low-temperature ovens to furnaces providing temperatures up to 1750°C, and include equipment for heating materials in air, in gas atmospheres, and in a vacuum.

The new factory has a floor space of about 40,000 sq ft and is arranged to provide two main bays, 190 ft in length, for the manufacturing and assembly work, including metal cutting and fabrication, the laying of insulating brickwork and refractories, and electrical installations. A machine shop occupies one side of the factory, while the stores, works offices, and canteen are housed on the other side. The fabricating section is well-equipped with machinery for sheet-metal working and for rolling angles and channels, and includes a guillotine with a 10-ft blade for cutting steel plate up to ½ in. in thickness and a hydraulic bending press for streamlined body construction, as well as an automatic profiling machine for making intricate shapes. Argon-arc welding equipment is installed for joining heat-resistant steels. A special feature in the electrical section is a furnace-testing panel, which enables a comprehensive check to be made on heating uniformity, electrical circuits, controls, and insulation. Modern equipment for cutting hard refractories and thermal insulation boards is installed in a dust-proof room.

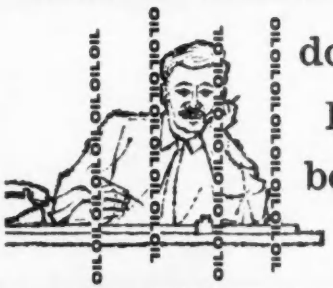
Second International Pipes, Pipelines, Pumps, and Valves Convention

A technical convention, the first of its kind to take place in Great Britain, will be held in conjunction with the Second International Pipes, Pipelines, Pumps, and Valves Exhibition at Earls Court, London from April 9 to 13, 1962. The convention will last four days, and will be divided into sessions, each representing a particular theme, as follows:—

(1) The scope, future, and legislative control of pipelines in the modern world.
(2) The manufacture, construction, and maintenance of steel and cast-iron pipe and pipelines.
(3) The manufacture, construction, and maintenance of other types of pipe and pipelines, e.g., non-ferrous, concrete, glass-fibre, plastics, and pitch-fibre.
(4) The operation and economics of oil pipelines.
(5) The operation and economics of gas pipelines, including underground storage.
(6) Pipelines for other uses, e.g., water, sewage, and steam.
(7) Specialized piping systems for chemicals, nuclear power, and the conveyance of solids.
(8) The instrumentation and automatic control of pipelines.
(9) Submarine pipelines.

It is proposed that each theme will be covered by

DESIGNERS-



do you long to be free?

Every time a designer sketches an assembly of moving parts he works within a constraint which has become so familiar that he scarcely recognises its existence. This constraint is the necessity to provide oil, grease, graphite or pressure lubrication for all sliding surfaces. GLACIER D.U. Bearings break this constraint.
THEY NEVER NEED OILING!

DU

Glacier D.U. is *NOT* a "self-lubricated" bearing material. It is LUBRICANT FREE and can withstand high and low temperatures (-200° to +280°C). It fills the demand for applications where it is inconvenient to lubricate or where contamination by oil and grease cannot be permitted. D.U. resists abrasive atmospheres and can operate submerged in liquids.

Glacier DU dry bearings consist of a steel backing on to which is sintered a layer of porous bronze impregnated with a mixture of fluoro-carbon plastic (P.T.F.E.) and lead

DQ

There are many applications where the remarkable properties of D.U. dry bearing materials are required but it is necessary to machine the effective surface. There are also shapes and sizes, notably very small components, which cannot conveniently be formed or pressed from a composite strip. D.Q., which is available in bars or tubes, combines the excellent frictional properties of solid P.T.F.E. with a thousand-fold improved resistance to wear.

Glacier D.Q. is an easily machinable dry bearing material consisting of a Fluoro-carbon (P.T.F.E.) strengthened with special fillers. Supplied from stock and in a range of standard bars and tubes.

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DESIGNERS!
Write for FREE Glacier Handbook No. 2, which deals with D.U. and D.Q. and which also describes the D.G. and D.L. process treatments.

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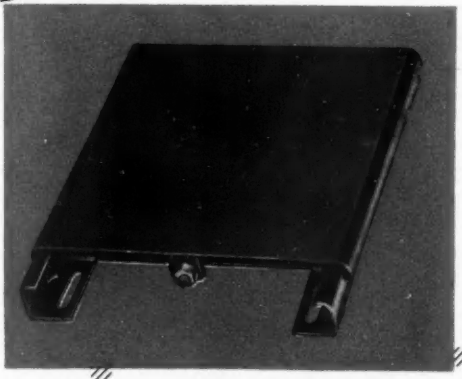
... Just a turn of the screw

corrects belt tension *while the motor is running with*

KENYON

Adjusto-Slide Motor Base



This all-steel motor base will replace slide rails and provide belt adjustments to fine limits ***without stopping the motor.*** It is robust and virtually foolproof, consisting of a rolled section fixed base and a sliding plate to which the motor is fastened. The motor can be moved through an infinite number of rigid positions by means of a single adjusting screw. Our catalogue PT 3 & 4 explains ADJUSTO-SLIDE MOTOR BASES fully. Please write for a copy.

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ECON-O-MATIC MOTOR BASES

Automatically matches the belt tension to each variation of load on the motor. Belt never too tight or loose. Slip eliminated.

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MB 1.

NEWS ROUND-UP

several papers by experts in their respective branches of the industry. At each session, abstracts only of the appropriate papers will be read, so that as much time as possible can be available for discussion. It is expected that speakers from many parts of the world will take part in the convention, and the Committee would be interested in receiving suggestions for papers on each theme for prospective speakers. Correspondence should be addressed to the Secretary, Mr. J. A. Oates, C.Inst.W., A.M.I.P.E., M.Inst.M., c/o Scientific Surveys Ltd., 97 Old Brompton Road, London, S.W.7.

Registrations for delegates to the convention are now being accepted (£3.3.0 each). Delegates will be admitted to the exhibition free of charge, will receive preprints of all papers, and will have the right to be present at all convention sittings and to take part in discussions on individual papers. Applications for registration as delegates should be sent to Scientific Surveys Ltd. at the above address.

Helically Welded Aluminium Pipe

The large-scale production of aluminium pipe in sizes up to 28-in. diameter is now possible as a result of the successful adaptation of the helical-weld principle of tube manufacture. The two main types of aluminium pipe available in large quantities, i.e., extruded and drawn seamless pipe, have been limited by practical considerations to a maximum diameter of about 12 in., while the method sometimes used to fabricate large-diameter pipes by bending plates into cylindrical shapes and then welding them longitudinally does not lend itself to large-scale production.

The method of making helical-weld pipe essentially consists of feeding metal strip into formers or a series of rollers set at an angle, so that the strip describes a helix as it travels through the machine. The resulting helical seam is then welded continuously and automatically. The process, which enables pipe to be made in large diameters and great lengths, and to accurate limits, was first developed for steel pipe at the end of the last century, but it took many years of improvement in strip quality, in automatic welding techniques, and particularly in continuous weld testing and quality control before the production of consistently high-quality helical-weld pipe became a practical proposition. Because of the increasing demand for thin-walled aluminium pipe in large diameters, Alcan Industries Ltd. (then the Northern Aluminium Company) undertook in 1959, in collaboration with makers and operators of helical-weld equipment, a programme of development work on the production of helical-weld aluminium pipe. The close tolerances to which aluminium strip is supplied permit welding to take place under excellent edge-matching conditions, and this is an important point which has contributed significantly to the success in making aluminium helical-weld pipe of consistently high quality. Moreover, welding is faster with aluminium than with steel, and the high speeds possible lead to high rates of output and low manufacturing costs.

Helical-weld pipe is now being offered in sizes from 6 to 28 in. diameter, with wall thicknesses up to ¼ in., by three British companies, i.e., Apitubes Ltd., Bristol Aerojet Ltd., and The British Steel Piling Co. Ltd. Apitubes Ltd. are producing pipe on helical-weld equipment designed and built at their Jarrow-on-Tyne works. Bristol Aerojet Ltd. have developed a different type of machine which produces helical-weld pipe to exceptionally close tolerances for the more specialized types of application, while The British Steel Piling Co. Ltd. are operating a "Driam" helical-weld machine at their Claydon Works, near Ipswich. On the Continent at Oberhausen, near Dusseldorf, Intercontinental Enterprises G.m.b.H. are building their "Heliweld" plant, which will be capable of forming pipes up to 120-in. diameter from strip up to ½-in. thick. It can therefore be used for making cylindrical vessels and tanks, as well as pipes.

Stress-Relieving Furnace for Large Fabrications

Measuring 27 × 27 × 80 ft in length and believed to be the largest of its kind in the world, a new electric stress-relieving furnace is being installed by Head Wrightson Teesdale Ltd., a subsidiary of Head Wrightson & Co. Ltd., at their Thornaby-on-Tees works. The furnace, which was designed by Cooper Electroheat Ltd., is capable of stress-relieving large fabrications such as oxygen steel converters and will be used in the fabrication of the boilers for the nuclear power station at Dungeness. Although it is not yet complete, the furnace has already been used for stress-relieving fabrications weighing 50 tons.

An important feature of the furnace is that no firebrick is used anywhere in its construction. The hearth, walls, and roof are made generally from mild-steel panels measuring 8 × 8 ft, filled with compressed mineral-wool slabs and secured with flexible mild-steel sheeting. The roof panels are fixed to longitudinal rolled-steel joists at roof-truss height. The side walls, carried by A-frames and mounted on bogies, are easily retractable, and the end walls can be lifted into position in two sections by means of a mobile crane. The furnace is designed in such a way that it can be dismantled and re-erected elsewhere or altered to admit smaller or larger fabrications.

The fabrications to be stress-relieved are supported on cradles and carried on bogies which also carry the furnace floor. Longitudinal expansion of fabrications is taken up by individual bogies which move relative to each other. The 1500-kW electrical elements, operating at mains voltage, are arranged in units of 40 kW, each unit comprising twelve coiled elements in sintered-alumina sleeves supported in stainless-steel channels. These channels rest on a mild-steel framework placed on the furnace floor, which is also made in panel form. Heating is effected by convection currents of hot air inside the flueless closed furnace, so that oxidization of fabrications is negligible.

Classified Advertisements

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NEW 200-TONS PRESS BRAKE FOR SALE. IMMEDIATE DELIVERY, subject to prior sale. Thickness formed ¼ in. to 167 in. over 2 in. die opening. Maximum working length 13 ft. 11 in. Between uprights 11 ft. 8 in. Steel plate construction. Motor drive. Weight about 25½ tons. An excellent machine. Full details, illustrations from:

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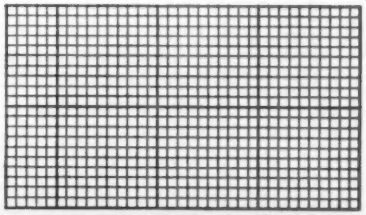
Sections by the thousand

Whatever the shape, Metal Sections can cold roll it accurately to any required length or quantity. Thousands of standard sections are available, but if you demand an entirely new shape our designers will be glad to help.

Sketch your section for us—
we will quote without obligation.



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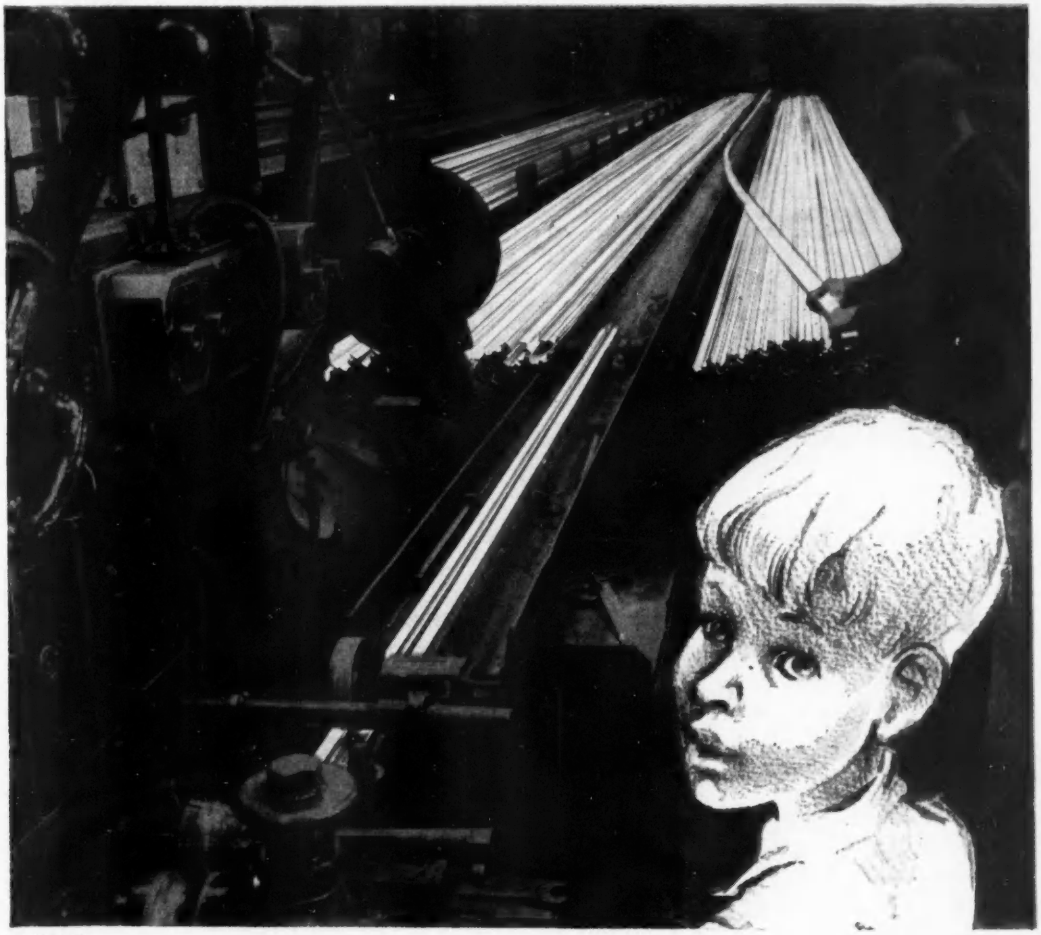

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LATEST INDUSTRIAL LITERATURE

Materials

1. High-Strength Steels

Details of chemical composition, mechanical properties, and recommendations for cold and hot forming, welding, punching, shearing, and gas-cutting of a range of high-strength steels are given in a 12-page brochure. The steels have greater abrasion resistance and about 40% higher mechanical strength than ordinary structural carbon steels.

2. Die Steels

Recommended for the hot pressing of steel and brass, for cold drawing, hot extrusion, cold shearing, and for diecasting and plastic moulds, a range of die steels is presented in an 8-page brochure. Information on the selection of die steels, on operational temperatures, and on shock conditions is included.

3. Asbestos Moulding Materials

A 28-page brochure contains particulars of resinated asbestos moulding materials which are claimed to be tough, light, dimensionally stable, and to have high flame and acid resistance. Applications include high-pressure cured felts which can be turned, milled, and drilled, high-pressure moulded felts, laminates, flocks and powders based on asbestos fibre, etc.

4. Plastic Linings

Details are presented in a 12-page brochure of a range of plastic lining service developed for covering metal vessels and components with a thermo-setting and thermo-plastic corrosion-resistant lining. The coatings provide long-lasting highly-glazed surfaces which are easily cleaned and sterilized, and are odourless and tasteless to satisfy the needs of a wide range of chemical and processing industries.

Castings

5. Steel Castings

Specifications, properties, and applications of a wide range of steel castings are listed in a 24-page brochure. Examples of castings described include driving sprockets, cross beams, stub axles, pivot brackets, bevel pinions, track shoes for excavators, mine-car wheels, rocker arms for coal-cutting machinery, and locomotive wheel centres.

6. Casting Design

Recommendations for improving casting design and reducing the cost of castings are given in a 6-page folder, dealing with problems of reducing moulding, core-making, cleaning, and machining costs, as well as decreasing weight and increasing dimensional accuracy.

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120 Wigmore Street, London, W.1.

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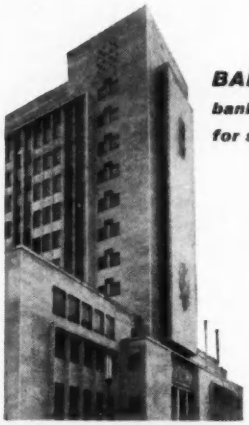

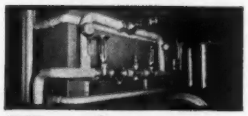

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for steam pressure regulation

The entire pressure regulation system at Barclays Bank D.C.O., Goodenough House, Old Broad Street, London, was supplied by Sir W. H. Bailey & Co. Ltd. for the Consulting Engineers, J. E. Greatorex and Partners, and the Heating Engineers, Sulzer Bros. (London) Ltd. The architects were Ley, Colbeck, and Partners. While specialising in the manufacture of pressure regulators, Bailey's are in a position to supply complete installations of this kind, incorporating isolating valves, strainers, relief valves, gauges and ancillary equipment. For medium and low pressure control installations in steam, water, oil, air and gases, you can bank on Bailey's.

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LONDON & SOUTHERN AREA SALES:
Selinas Lane, Dagenham, Essex. Tel: Dominion 2277 (3 lines)
PRESSURE REGULATORS · SLUICE VALVES · TEST PUMPS · TURNSTILES
TGA G48

7. Centrifugal Bronze Castings

A 6-page folder contains details of centrifugal bronze castings, describing the process of casting, the cost factors, the sizes of castings available, as well as the mechanical properties, surface finish, and chemical composition of the bronze castings. Information on the various alloys suitable for the centrifugal-casting process is also incorporated.

Welding and Brazing Equipment

8. Low-Heat Metal-Joining Electrodes

Suitable for producing strong low-temperature joints between dissimilar metals, a range of low-heat metal-joining electrodes is introduced in a 6-page leaflet. The electrodes are suitable for welding, brazing, and surfacing steel, cast iron, bronzes, silver alloys, light metals, and are claimed to provide strong joints without cracks and distortion.

9. Welding Equipment

A wide range of welding equipment described in a selection of brochures and leaflets includes welding rectifiers for inert-gas welding, oil-cooled welding transformers, high-frequency ionizers, and a range of aluminium, bronze, stainless steel, and special high-speed electrodes.

Motors and Control Gear

10. Industrial Motors

Particulars of ratings, horse powers, speeds, starting characteristics, and temperature rises of a wide range of totally-enclosed a.c. motors are given in a selection of brochures. Additional brochures contain details of protected, drip-proof, and louvre-ventilated d.c. motors from 1 to 30 hp output at 1000 rpm.

11. Contact-Less Control System

Relying on the static switching properties of semiconductors, a contact-less control system is presented in a 20-page brochure. The components of the system are logic units and amplifiers, which combine, sort, and magnify input signals, the combination of these units performing the functions of any relay system. The units are totally encapsulated, and, having no contacts or moving parts, require no maintenance whatever.

12. Oil-Free Geared Motor Units

Covering output speeds of from 141 to 820 rpm and torques of from 49 to 212 lb in, a range of oil-less geared motor units is described in a 2-page leaflet. The units are single-stage epicyclic reduction trains built into the end shields of electric motors, which are sealed for life, quiet in operation, and free from vibration.

Pumps and Compressors

13. Industrial Pumps

The range of pumps described in a 4-page brochure includes gear pumps with deliveries of from 18 to 12,000 gph, vane pumps, paddle-displacement pumps, motorised sud pumps, petrol dispensing pumps, etc. An additional brochure contains information on turbine pumps, applications of which include fire-fighting equipment, water supply, test-bed cooling systems, etc.

14. Rotary Compressors and Vacuum Pumps

A selection of brochures and leaflets contains particulars of a range of oil-free compressors and vacuum pumps. The units have balanced rotors which operate without frictional contact and minimize wear, and special seals operating on renewable sleeves to provide adequate protection against entry of oil or gas leakage.

15. Automatic Pump Traps

Designed to deal with fluids from vessels under atmospheric pressure or vacuum, a range of automatic pump traps is described in a 4-page leaflet. An additional leaflet contains details of piston-operated and direct-operation steam traps and of separators which will divert the condensate to the steam trap from the steam line.

Industrial and Workshop Equipment

16. Fully-Guarded Diecasting Machines

Incorporating a fully-interlocked safety guard directly linked with the die-closing valve, replaceable bronze bushes for all main bearings, and disc valves on shooting cylinder, a series of diecasting machines is described in a 4-page folder. The effective capacity of the machine is 1½ lb zinc per shot, and the air pressure required is from 80 to 125 psi.

17. Spark Machines

Providing high cutting rates and great accuracy in the production of intricate shapes, such as forging and wire-drawing dies, etc., a range of spark machines is described in an 8-page folder. The machines are claimed to have comparatively small electrode wear, cutting rates of up to 75 cu. mm per minute, and extremely simple methods of control and operation.

18. Hydraulic Valves

A selection of brochures contains details of hydraulic valves, such as hand-, foot-, solenoid-, or air-operated valves, self-honing control valves, and 4-way valves suitable for pressures up to 2 tsi. The 4-way valves can be used to control any double-acting cylinder having controllable pressure fluid fed to both ends of the cylinder and also for the control of a downstroking press with push-backs which are fully exhausted.

19. Air-Power Units

Developed for providing low-cost automation in a number of production processes, a range of portable and stationary air-power units is described in a 12-page brochure. The units are applicable to almost any kind of rotating tool and are specially suitable for set-ups in production drilling, burring, grinding, nut-setting, screwdriving, tapping, reaming, and positioning.

20. Cutting Tools

An illustrated 60-page booklet serves as a useful guide to the selection and application of a range of cutting tools, such as drills, taps, reamers, milling cutters, tool bits, etc. Charts of hardness factors, tool angles, and tables of morse taper shanks are included.

21. Sprayed Cutting Compounds

Eminently suitable for applications in dieboxes, penetration down the flutes of tools, covering of forming tools and dies, and for following moving work-pieces, a range of sprayed cutting compounds is described in a 4-page leaflet. The spray compounds also have useful applications in screw-cutting, press-work, sawing, slot milling, tapping, facing, and counter-boring, specially in machine tools not fitted with sud pumps.

22. Permanent-Magnet Chucks

Details of operation and performance of a wide range of permanent-magnet chucks are given in a 30-page booklet. Information on the design, installation, and maintenance of the magnetic chucks is given, and adaptor plates, chuck blocks, demagnetizers, and special magnetic fixtures are also described.

LITERATURE REVIEWED RECENTLY

23. Engineers' Tools
24. Gunmetals for Quality Castings
25. Steel Strip and Bright Steel Bars
26. Sparkless Switches
27. Industrial Engines
28. Heavy-Duty Vertical Hobbing Machines
29. Remote Controls for Fullway Valves
30. Electric Motors
31. Silicone Rubbers
32. Hydraulic Pumps and Valves
33. Fibreglass Sheet, Strip, and Rigid Sections
34. Pneumatic Control Equipment

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Precision Grinding Machines

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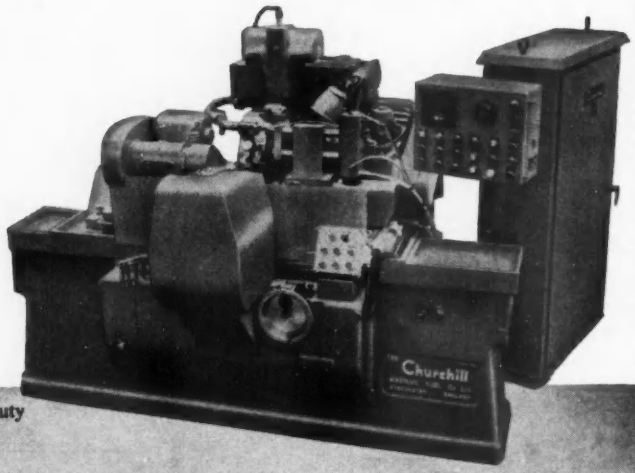
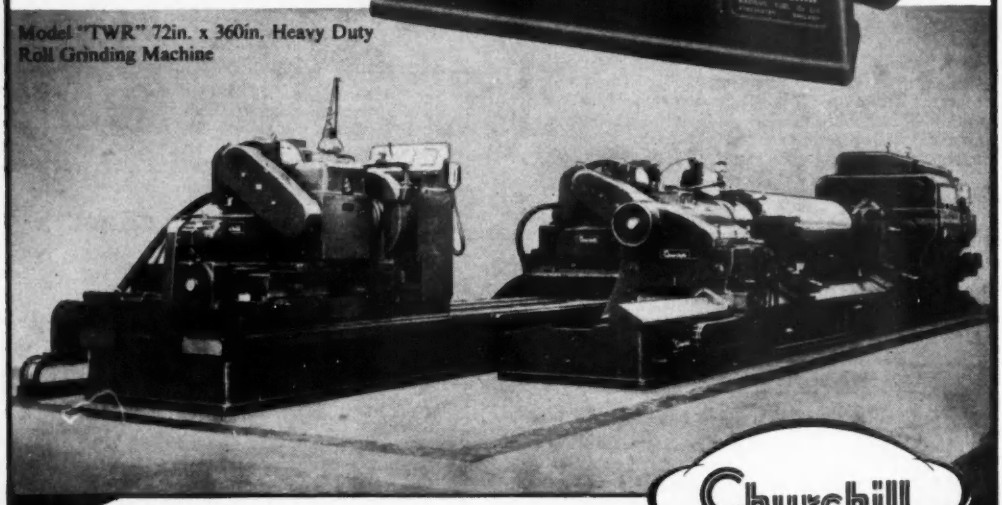


Model "TWR" 72in. x 360in. Heavy Duty Roll Grinding Machine



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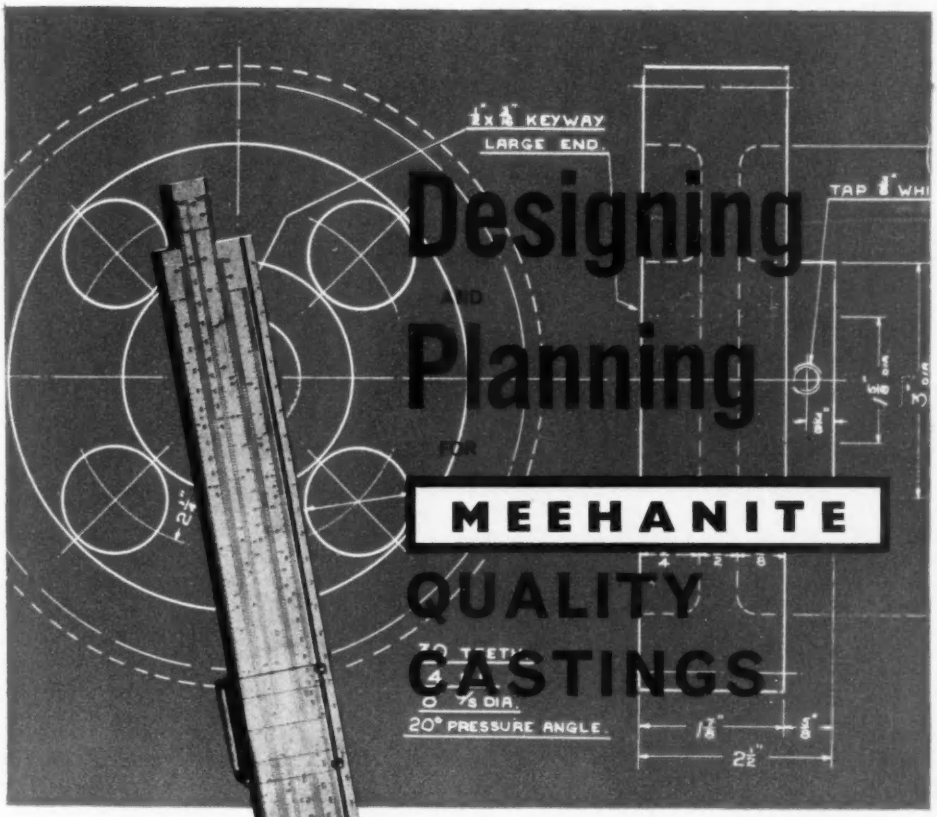

Designing AND Planning FOR MEEHANITE QUALITY CASTINGS

TAKE ADVANTAGE OF THIS FREE OFFER

Copies of this new bulletin will be sent free on request, please write for:

B6 Designing and planning for Quality Castings.

using the Meehanite Recommended Procedures

These have been compiled for the guidance of designers, engineers and buyers in a recent bulletin. This publication contains useful and practical notes on Designing the casting, Selecting the metal, Choosing the pattern, and Planning for low-cost production. Readers of this bulletin will find it of value in obtaining high quality Meehanite castings.

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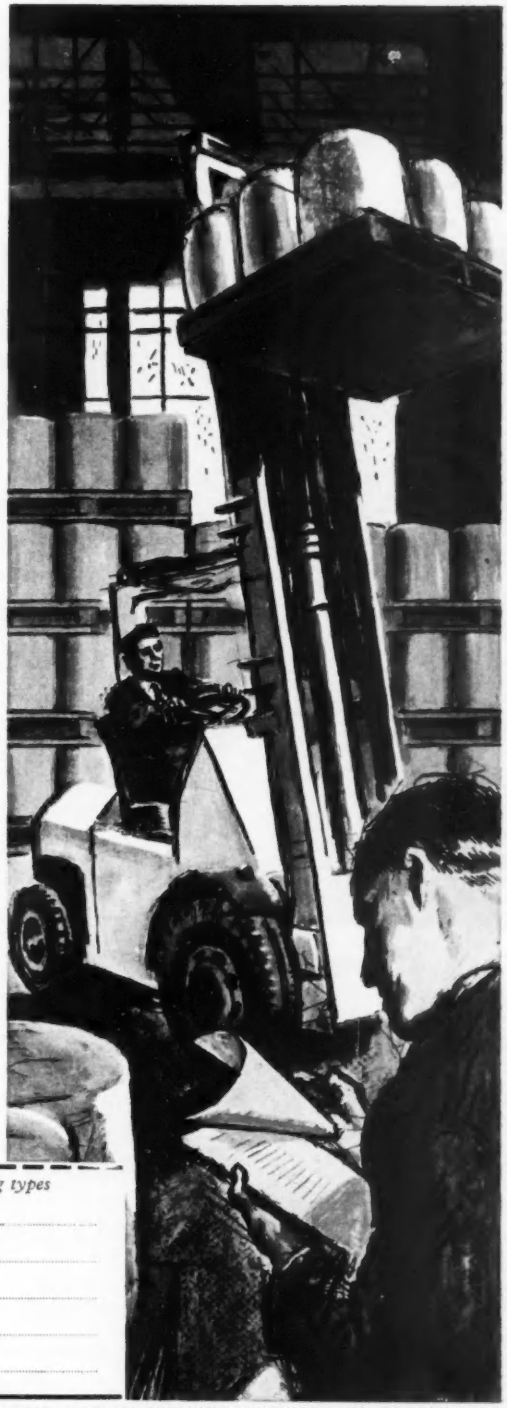

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Please send me details of Ford-powered equipment of the following types

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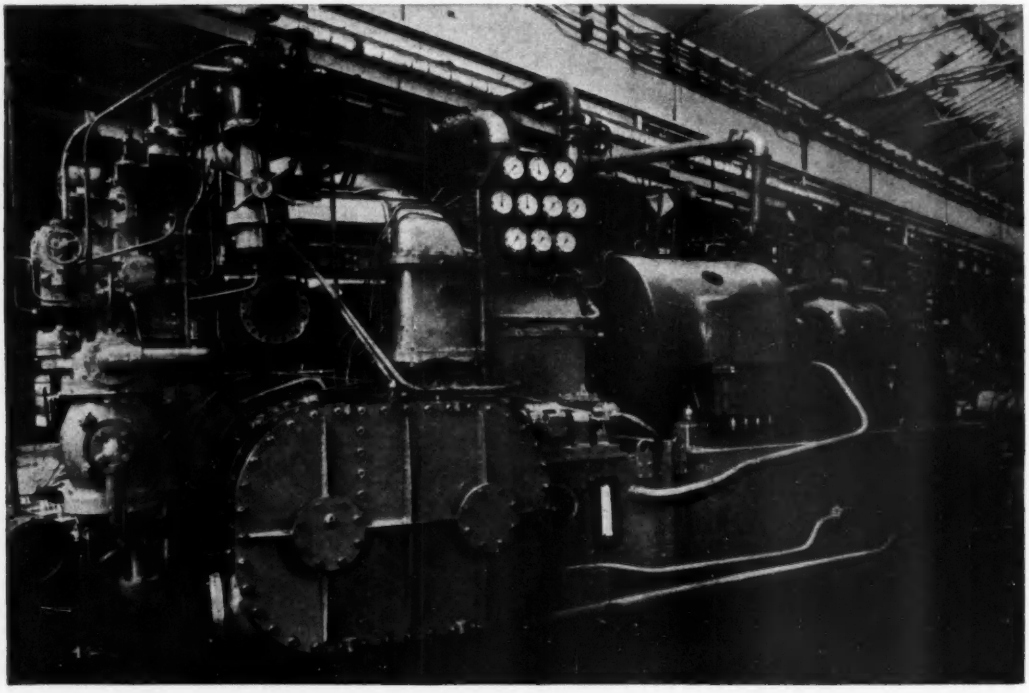

BROTHERHOOD 765 kW TURBO ALTERNATOR

Powered by surplus steam
from the "waste-heat" boilers of the
gas producing plant,
supplies all the electrical power needed at
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Power Plant Specialists on use of waste steam to provide electrical power at low cost.

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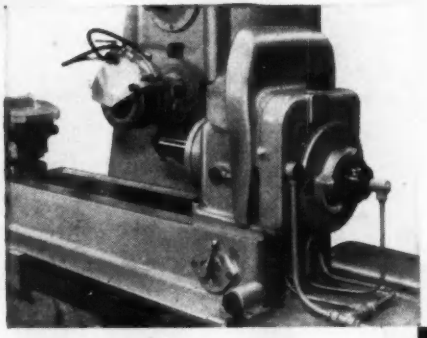
The Orcutt Hydraulic Shaft Grinding Machine was installed by Morris Motors Limited at their Coventry Works for accurate grinding of angular lug faces on syncromesh hubs for the new Wolseley 6-99.

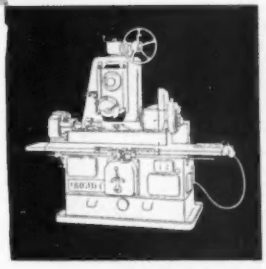
Write for our latest literature on the Orcutt 20" and 36" Grinding Machines.



Comprehensive gear grinding service.

Gears manufactured and ground complete.

Makers of the Orcutt range of gear and spline grinding machines and measuring machines.



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up to 400 kV
Three-phase ratings up to 600 MVA

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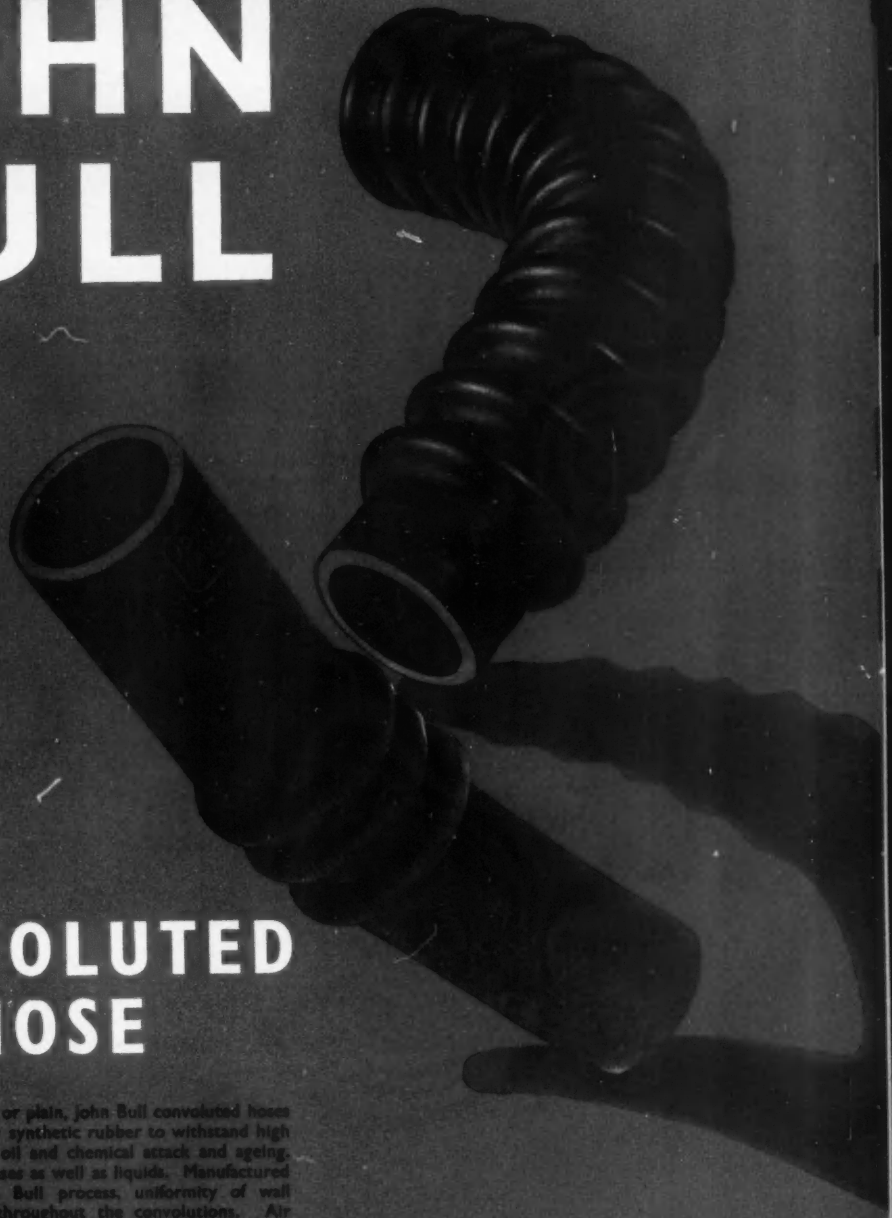

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Stockinette re-inforced or plain, John Bull convoluted hoses are made in natural or synthetic rubber to withstand high and low temperatures, oil and chemical attack and ageing. They are suitable for gases as well as liquids. Manufactured by the patented John Bull process, uniformity of wall thickness is retained throughout the convolutions. Air cleaner hoses are made to the same high standard.

All rubber hose is available in standard 4 ft. lengths in a range of diameters. Specially fashioned hoses can be manufactured to your requirements.

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Weir + Pacific

pumps

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WEIR — PACIFIC PUMPS

Centrifugal pumps for the petroleum, chemical, process and fluid handling industries.

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Heat, oil and petrol resistant
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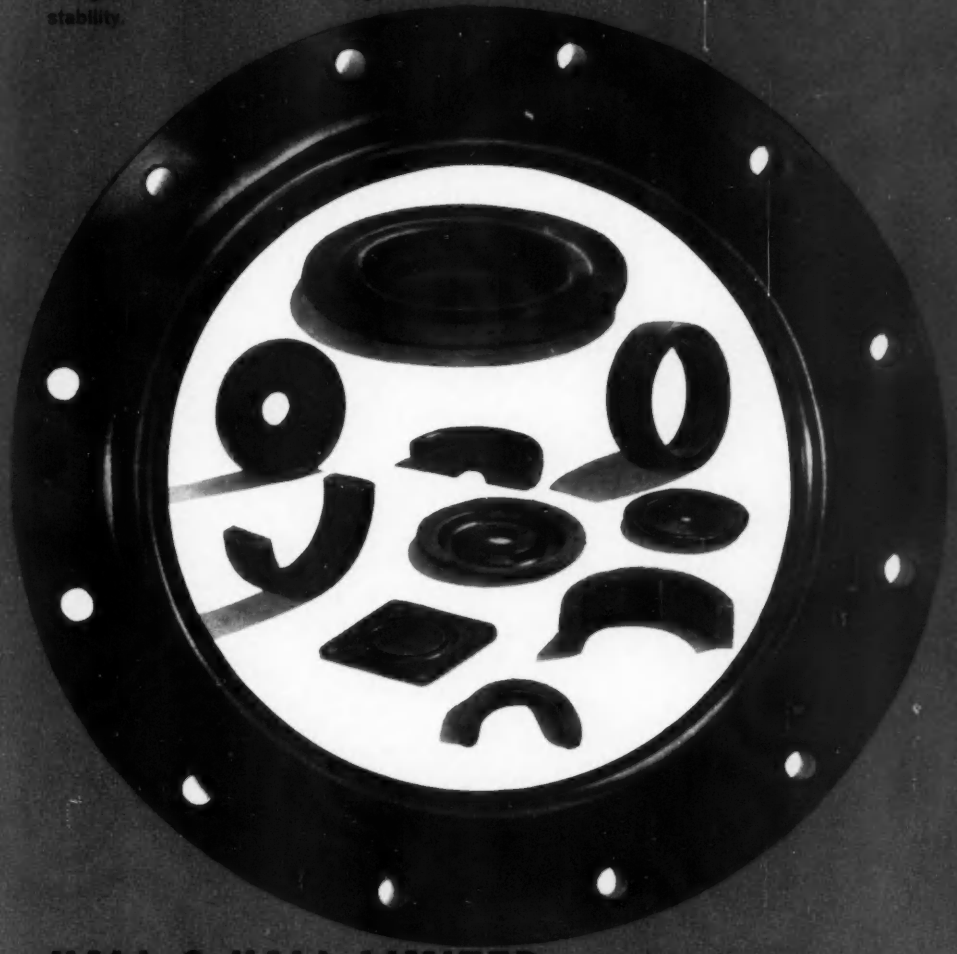

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The Weldmesh was specially produced to the specification of the Contractors for the superstructure. The A.C.D. Bridge Company, a consortium comprising Sir William Arrol & Co. Ltd., The Cleveland Bridge & Engineering Company Ltd., and Dorman Long (Bridge & Engineering) Ltd., the Consulting Engineers being Mott, Hay & Anderson, in association with Freeman, Fox and Partners.

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M-W.1042

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FRITZ WERNER Punched Tape Controlled Milling Machines are standard machines with special electrical equipment for tape control which does not prevent manual operation.

A standard teleprinter tape determines spindle direction and braking; variable feed rates including rapid traverse; direction and length of table movements. The standard feature of automatic hydraulic clamping of stationary slides ensures rigidity.

Automatic dividing attachments, circular tables and clamping fixtures can be included in the programme which can contain an infinite number of stages.

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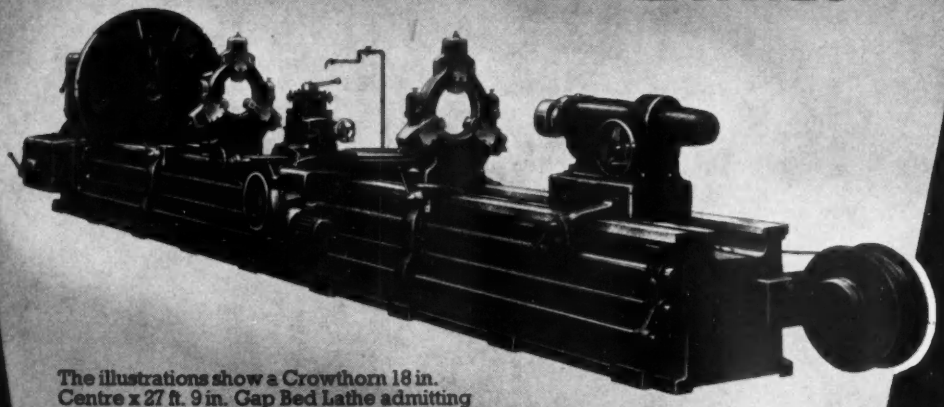
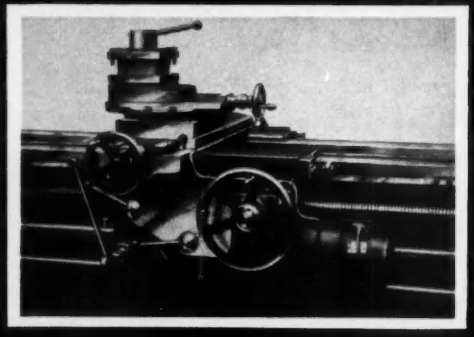
CROWTHORN

HEAVY DUTY LATHES



The illustrations show a Crowthorn 18 in. Centre x 27 ft. 9 in. Gap Bed Lathe admitting 20 ft. 6 in. between Centres and, inset, a view of the quick power traverse mechanism. The lathe is typical of Crowthorn Heavy Duty Long Bed Lathes.



some notable features of the lathe

1. Special heavy duty tailstock with built-in Timken roller bearing assembly.
2. Bed casting of very heavy section for rigidity and accuracy.
3. Quick power traverse to carriage by means of flange mounted motor and cable reel.
4. Heavy duty steadies with needle roller bearings.
5. Heavy duty grinding attachment available for mounting on cross slide in place of toolpost.
6. Taper turning attachment.
7. Micrometer dead stop.

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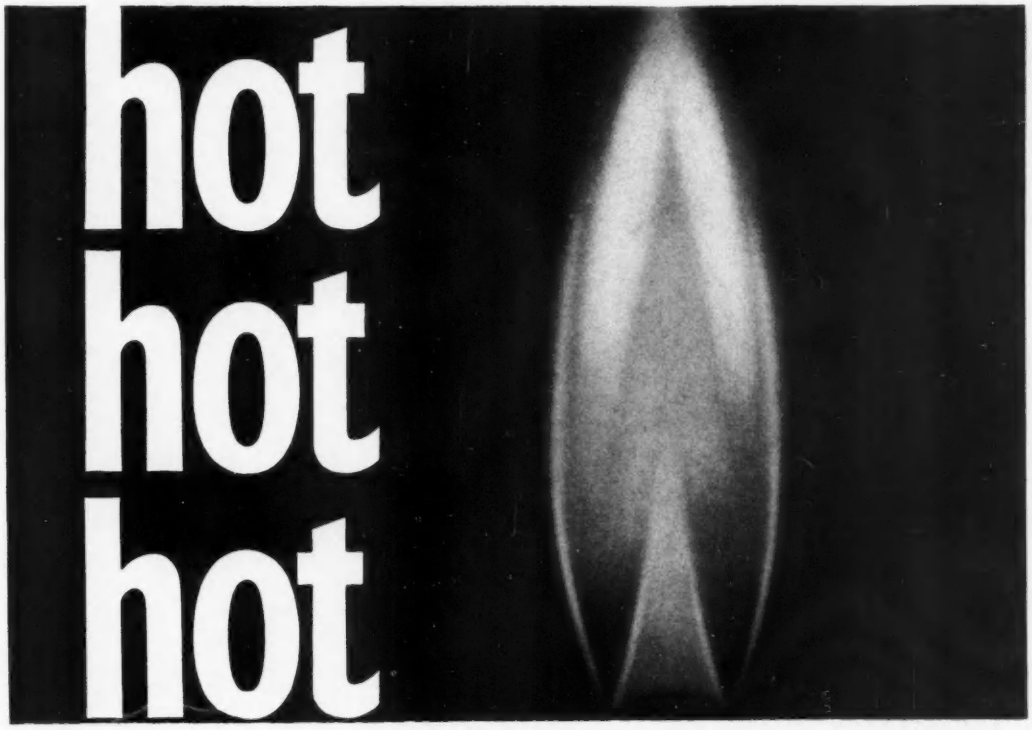

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Silastomer is the registered trade name of a comprehensive range of silicone rubbers manufactured and marketed by

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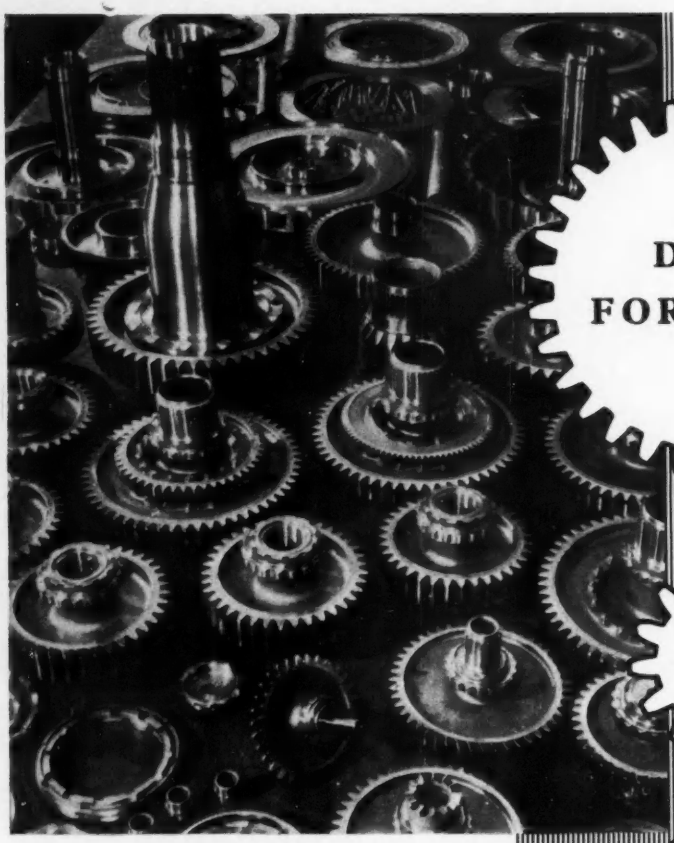

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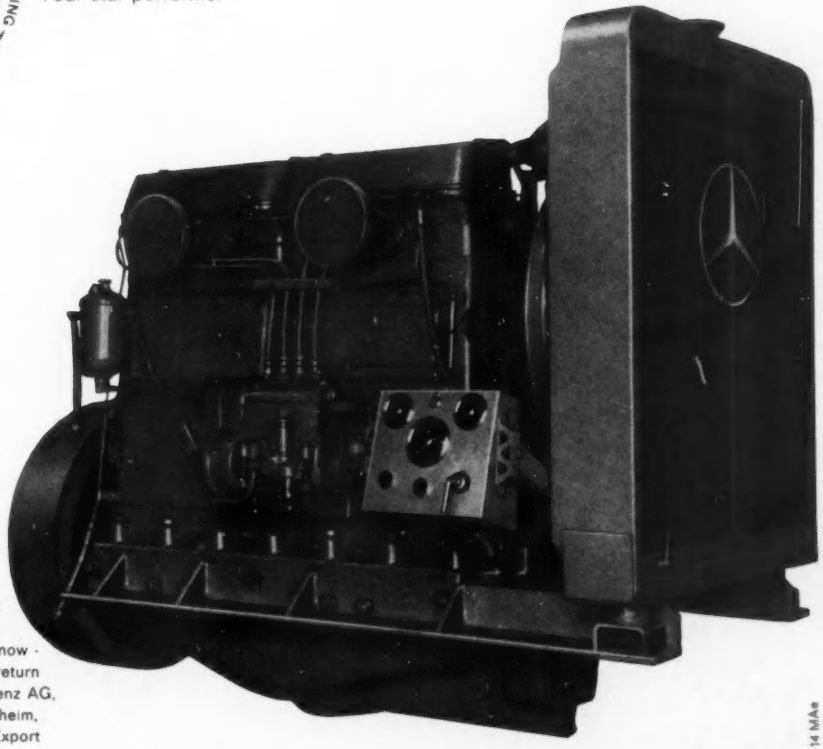

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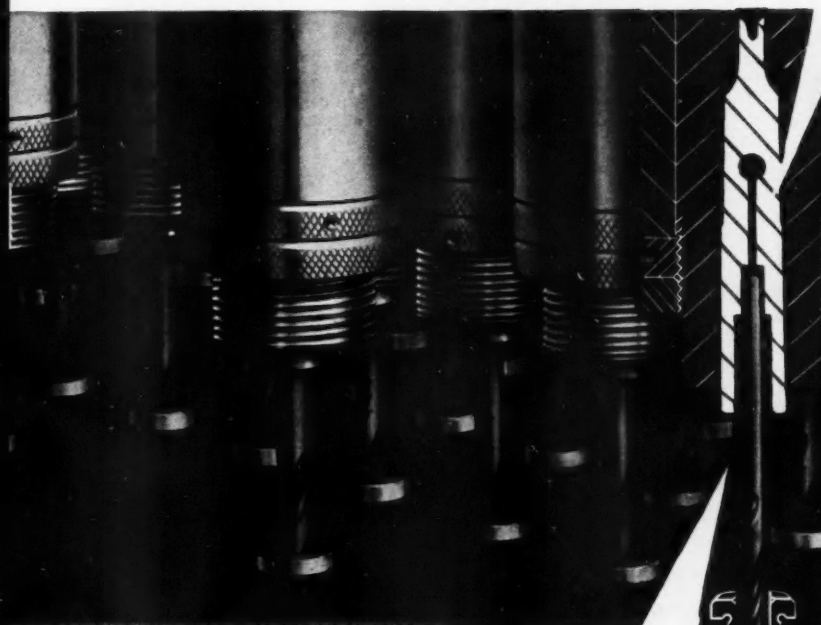

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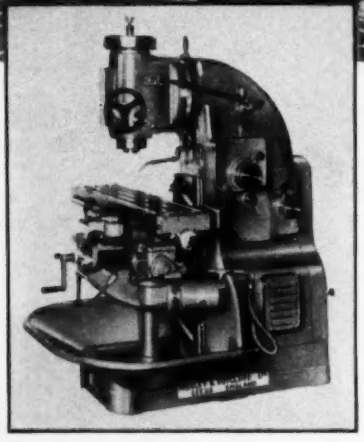

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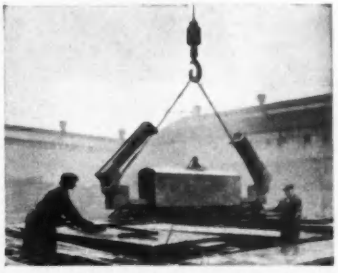

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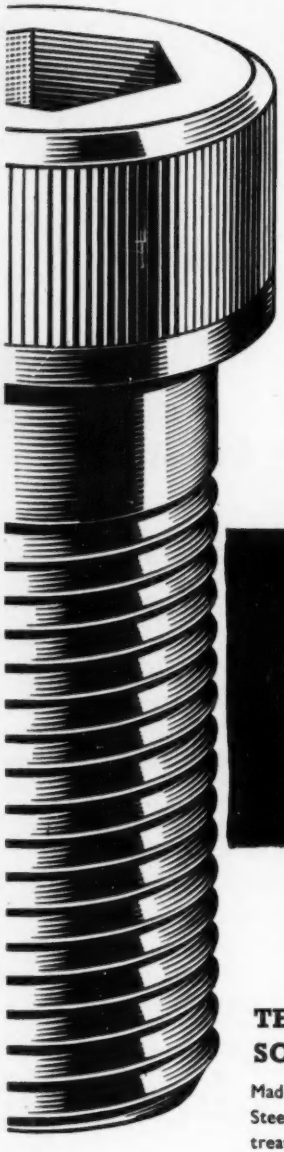

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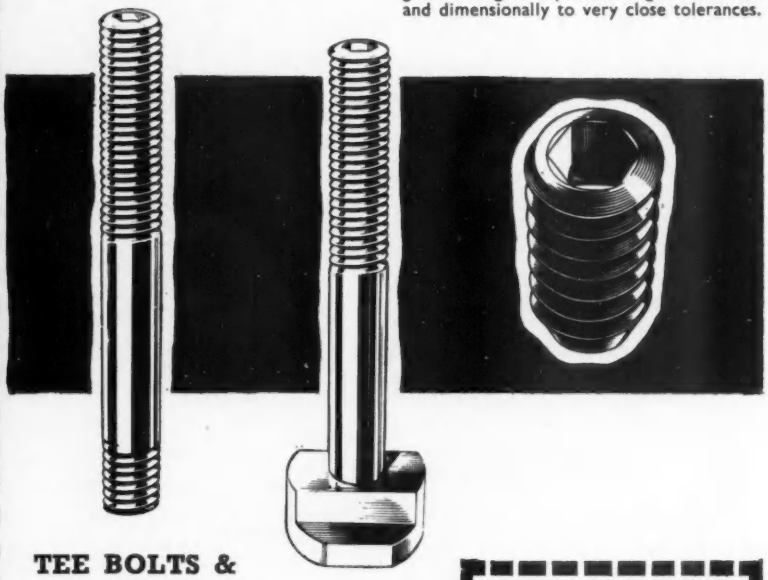

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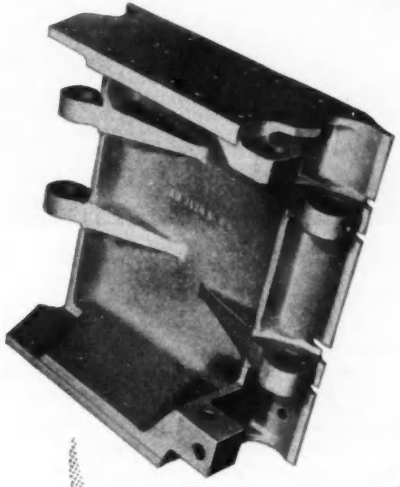

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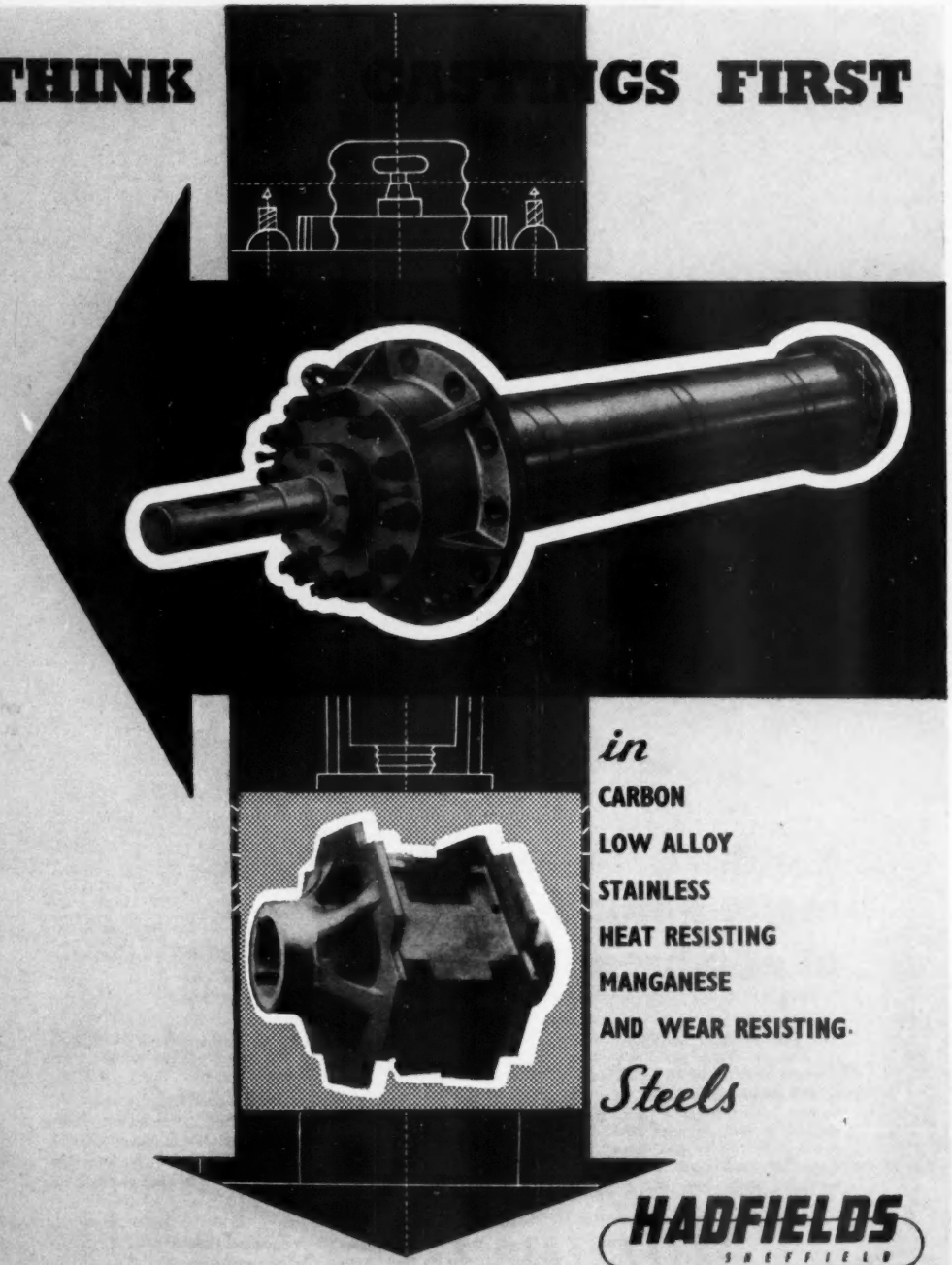

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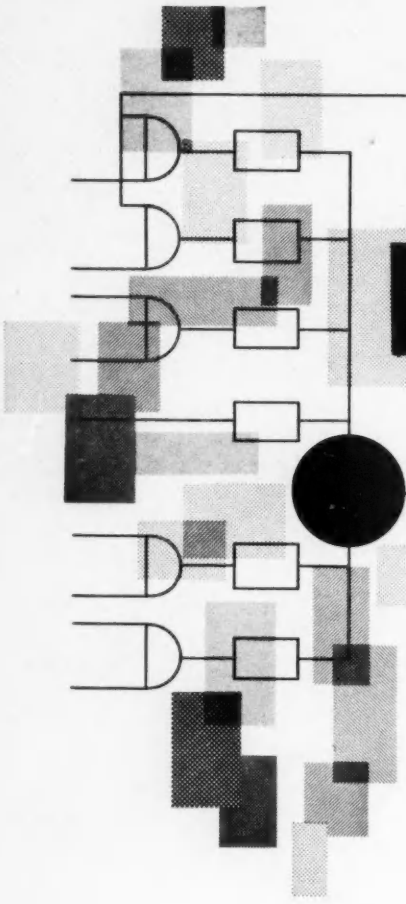

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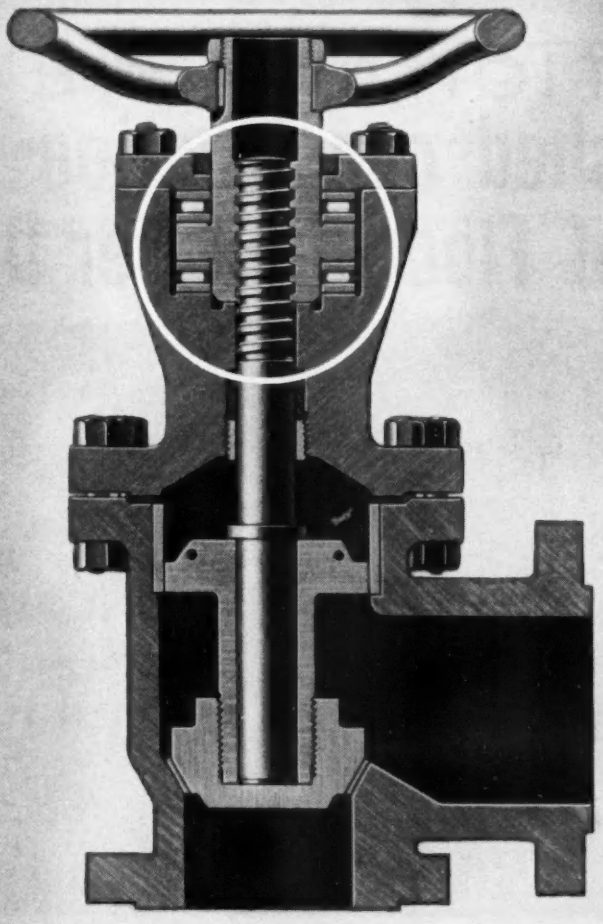

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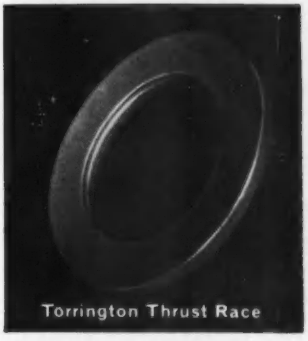

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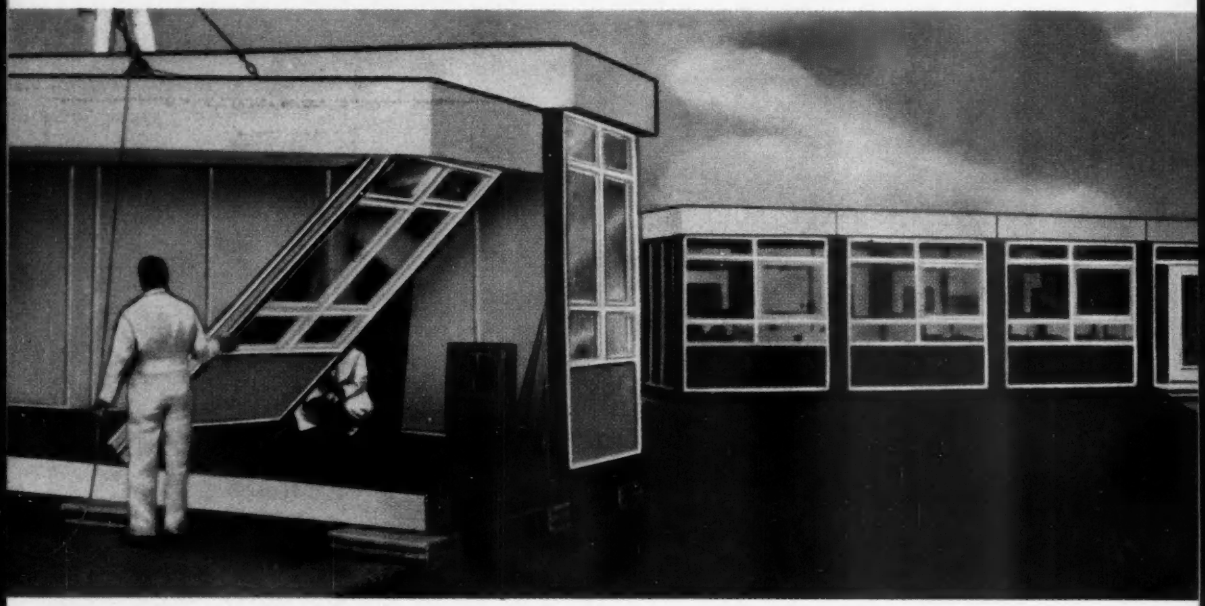

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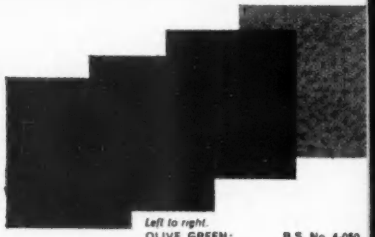

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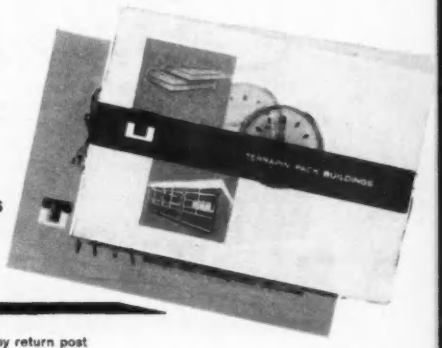

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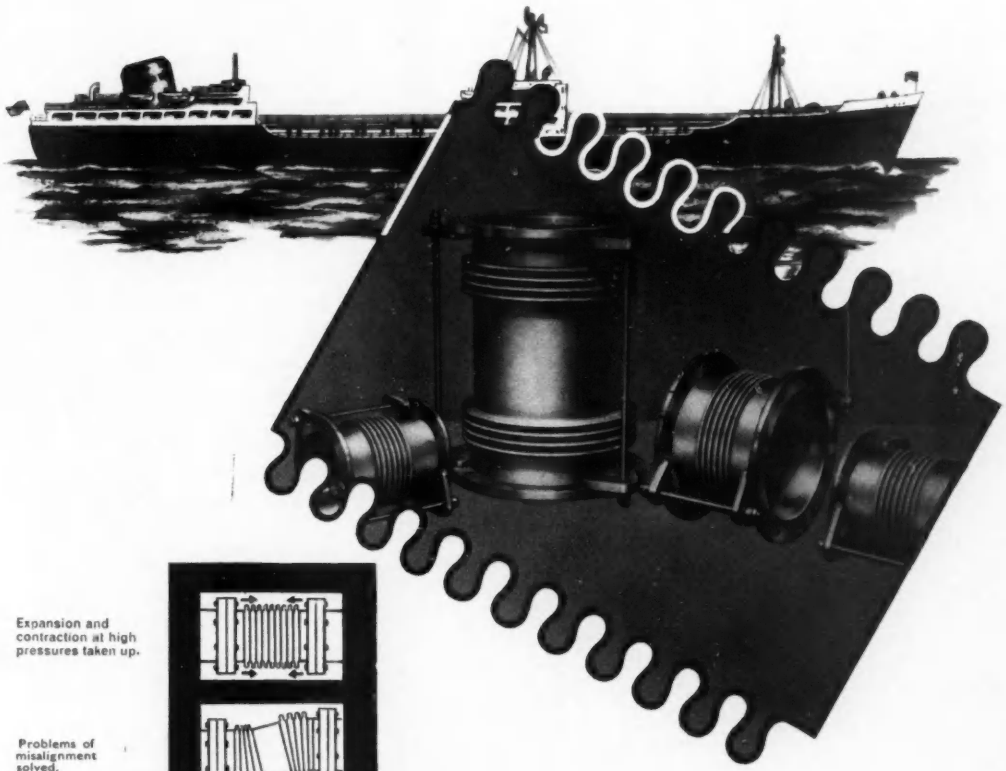
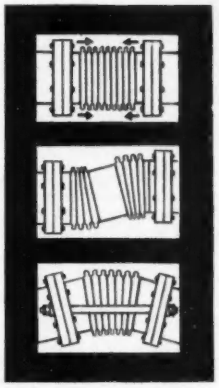
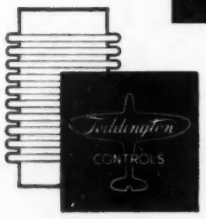




Expansion and contraction at high pressures taken up.

Problems of misalignment solved.

Angular movement in any plane accommodated.



Tankers and their internal pipelines present problems peculiar to their "calling". Expansion joints in the steam tank-heating systems and the increasing development of natural gas transport in tankers, brings in sub-zero temperatures and dismensional variation of pipelines. Teddington bellows joints are ideally suited to the mechanical conditions imposed and, too, cater for the corrosive conditions attendant upon these modern fuel handling problems at sea and at the discharge dock.

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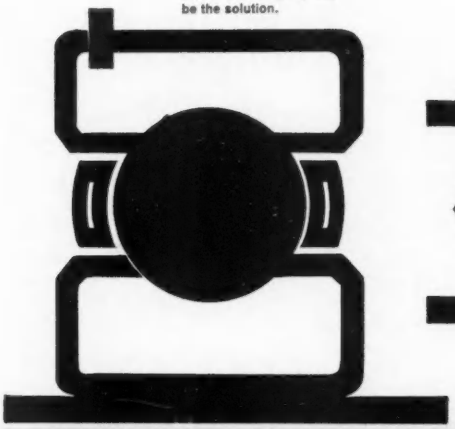
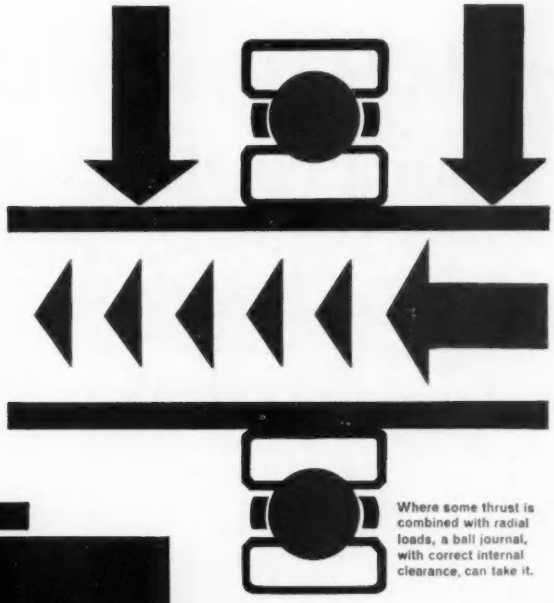
When location difficulties occur, an external circlip fitted to the bearing may be the solution.





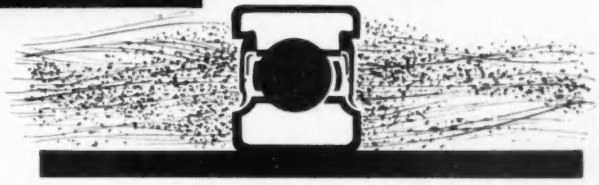
Where some thrust is combined with radial loads, a ball journal, with correct internal clearance, can take it.

R&M ball journals are versatile and adaptable

Quite often, opportunities to simplify and improve the efficiency of a design are missed — because the versatility of R&M ball journals has not been fully exploited. Their possibilities are not always appreciated. This is understandable since ball bearings themselves are an involved design study.

Further possibilities arise with notched rings for increased journal capacity, special manufacturing controls for high speeds, and special materials for high temperatures.

Next time you have a bearing problem, remember that Ransome and Marles Technical Department would be pleased to offer you expert, impartial and confidential advice.



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BEARING COMPANY LIMITED
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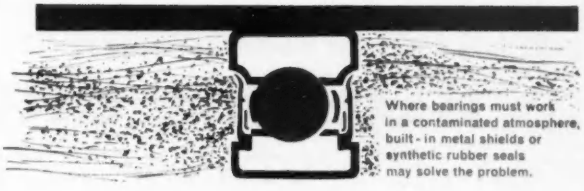
BALL & ROLLER R&M BEARINGS



Where bearings must work in a contaminated atmosphere, built-in metal shields or synthetic rubber seals may solve the problem.

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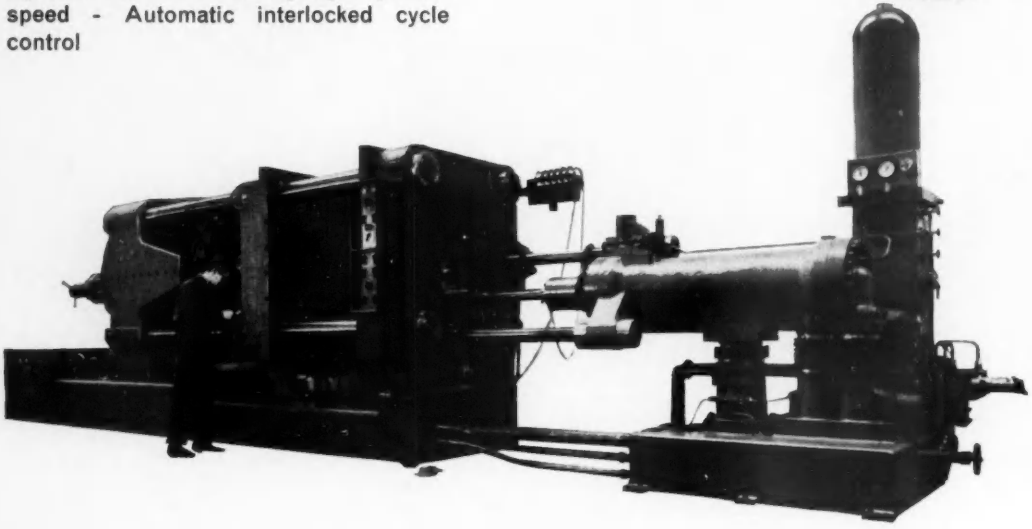

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Locking force: 800 tons
Injection force: 90 tons
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Space between tie bars: 33 × 37 in.
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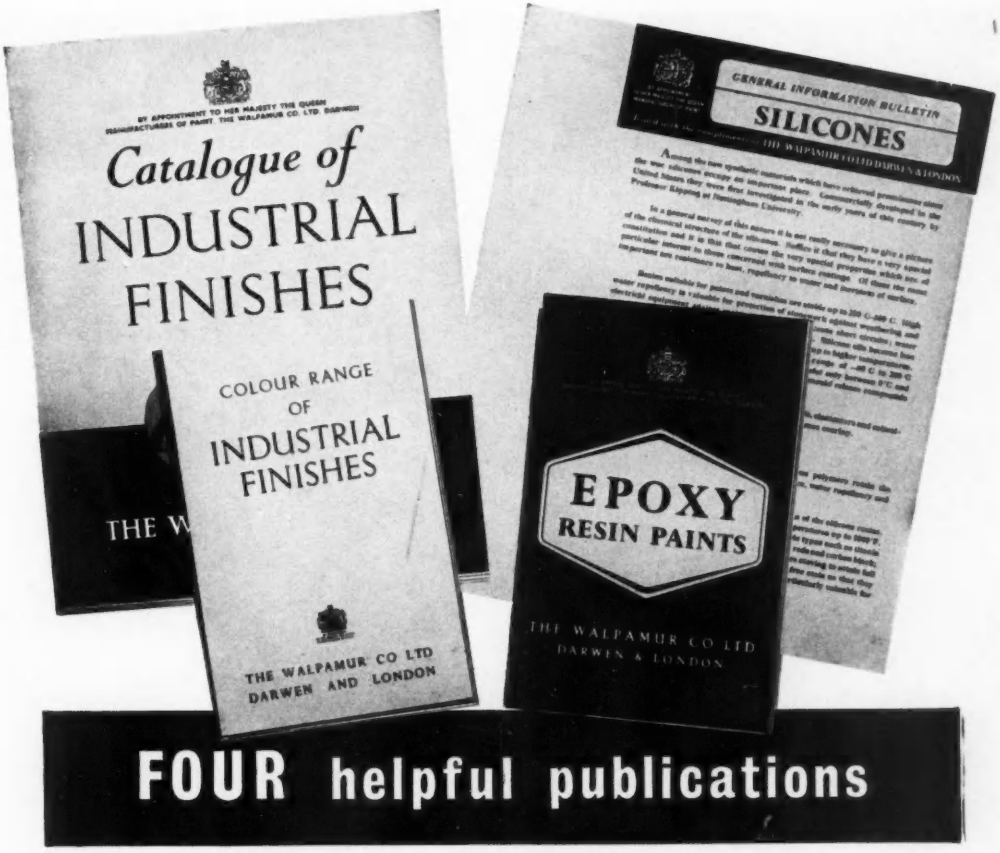

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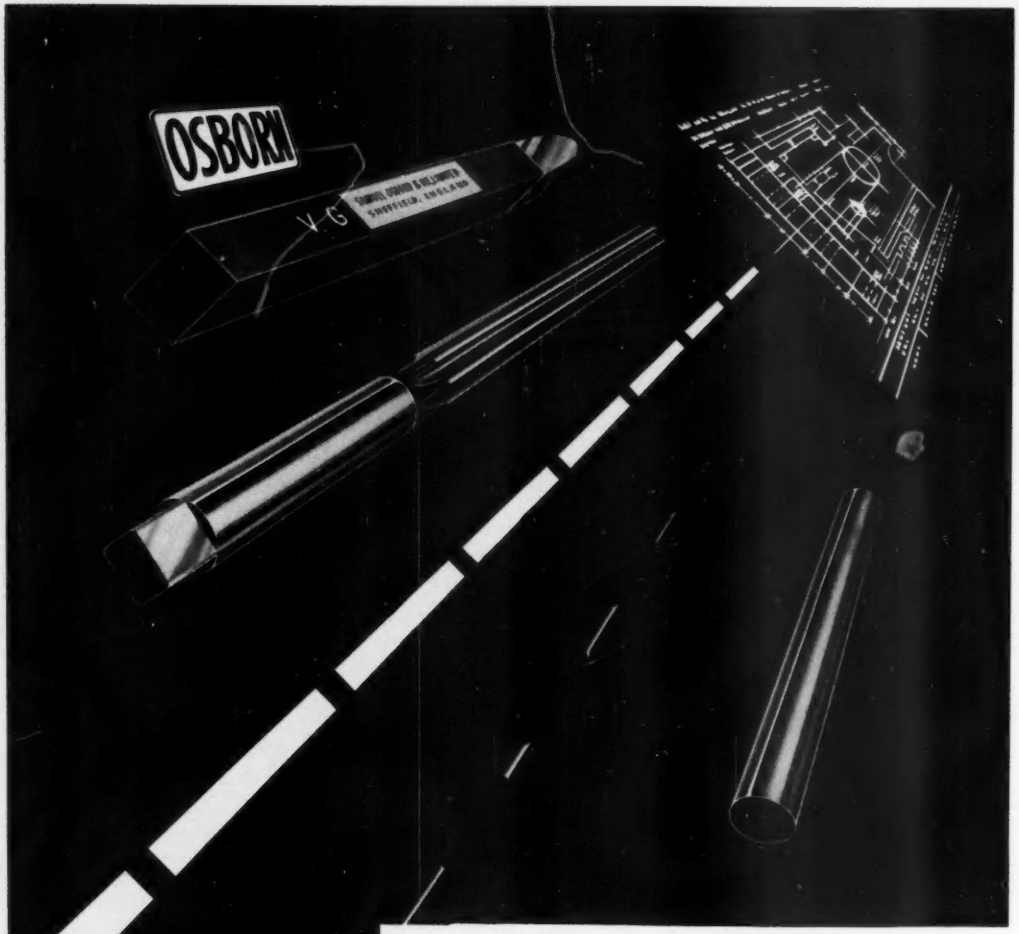

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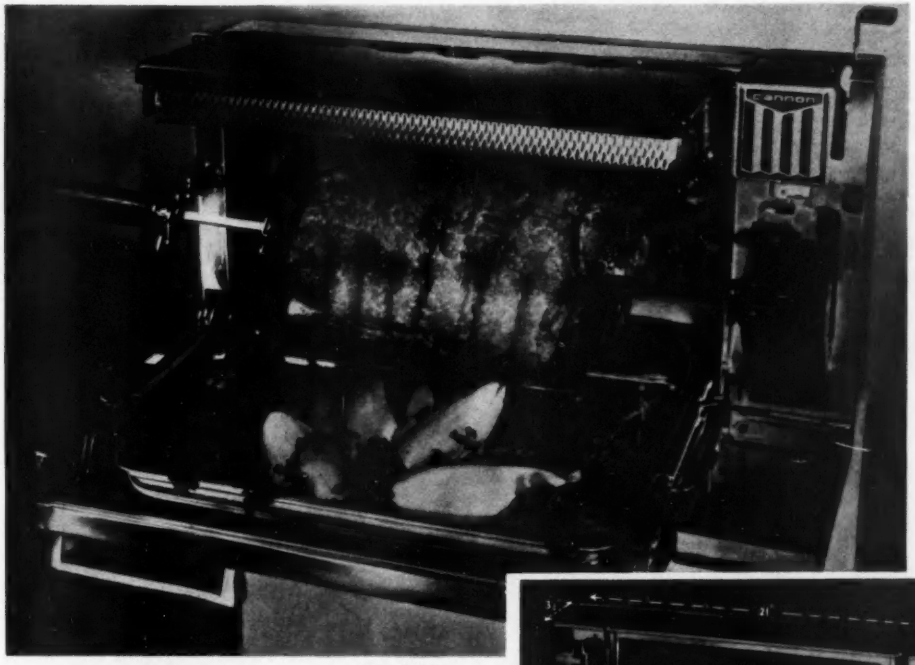

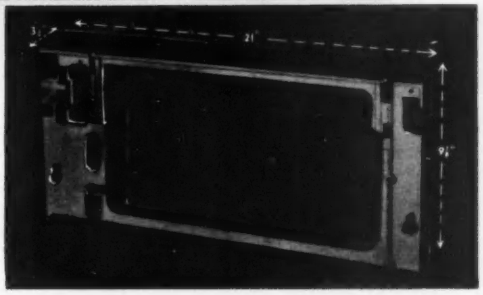

Main Grill Frame for Cannon "SuperChef" Rotisserie-Grill. Cast by Birmingham Aluminium Casting (1903) Co. Ltd., using (KE) A145 steel dies. Photograph by courtesy of Cannon Industries Limited.

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V10 B

Talk to Sykes about the V10 B . . .

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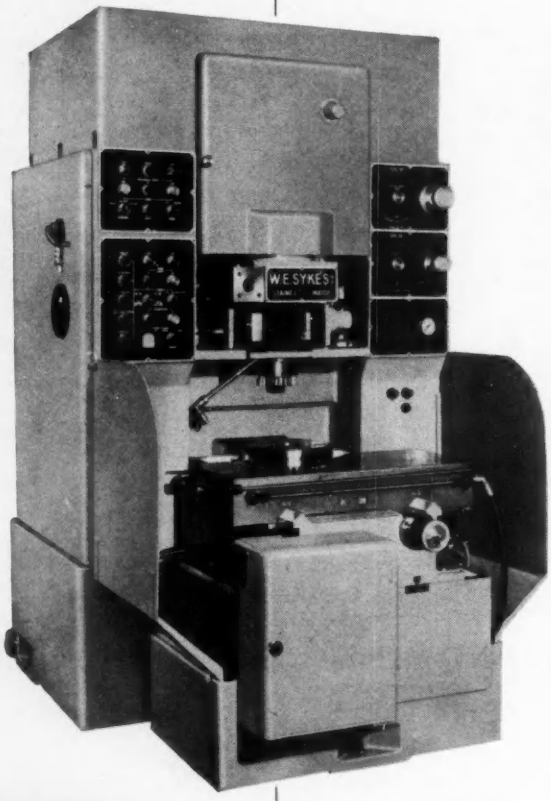

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TYPE OA

SPEED RANGE

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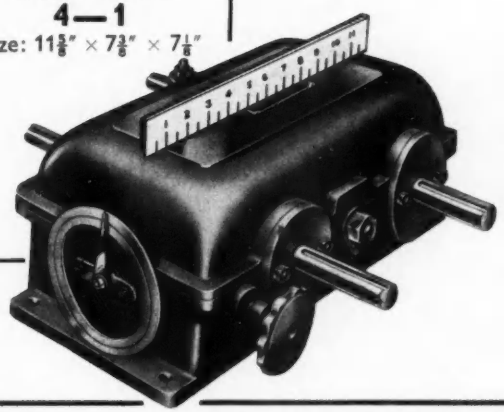
Size: $11\frac{5}{8}$" × $7\frac{3}{8}$" × $7\frac{1}{8}$"

The twelve inch rule indicates relative dimensions.



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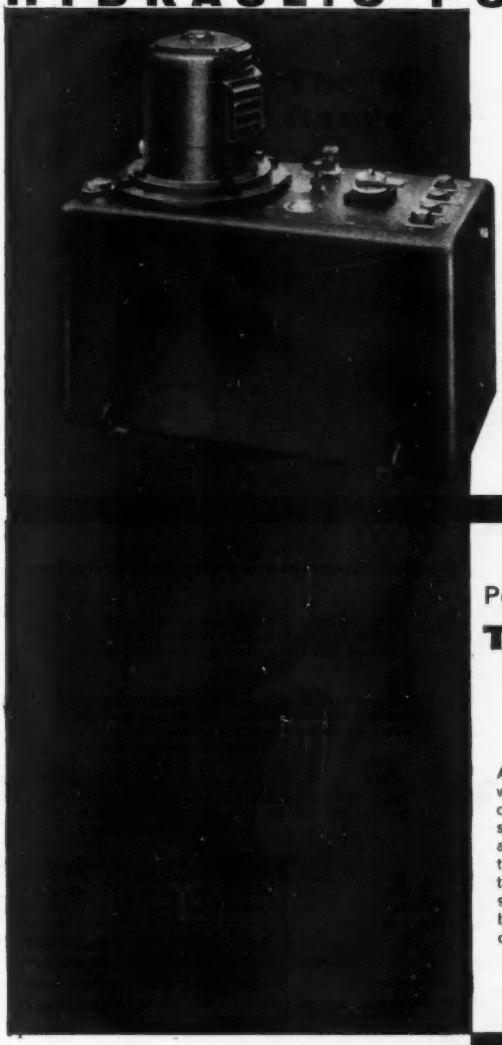

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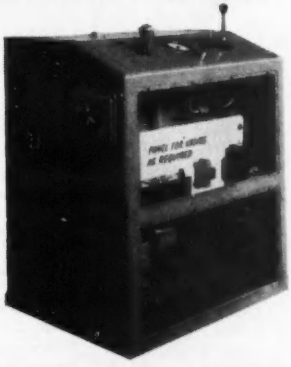

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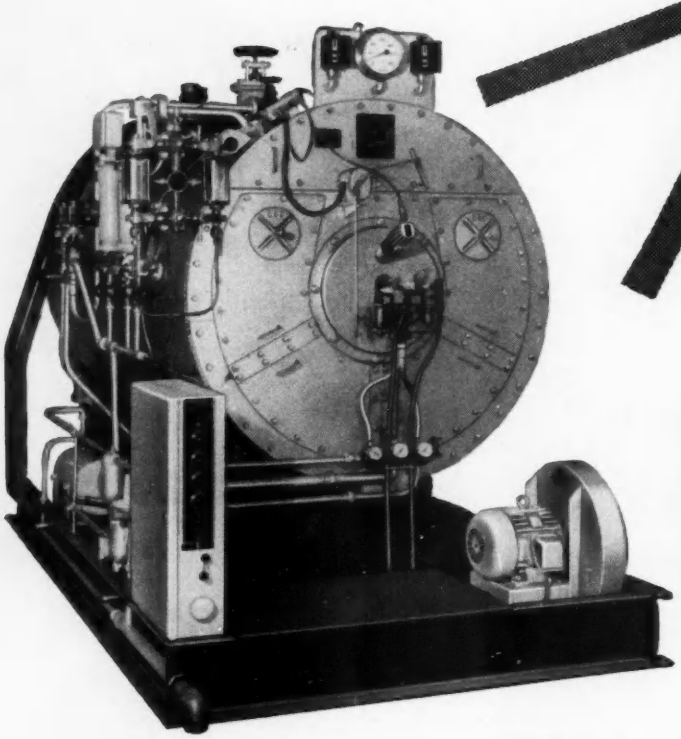

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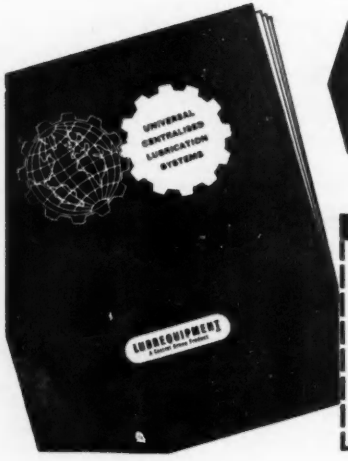

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THE BLUE PAGES

A QUICK GLANCE AT THE LATEST TECHNICAL DEVELOPMENTS THROUGHOUT THE WORLD

● *THE GROWTH RATE OF OXIDE FILMS ON COPPER*

To provide basic data on the mechanism involved in the corrosion of metals, the thin oxide films sometimes forming on metal surfaces during the corrosion process are being investigated. In the case of films formed on copper surfaces, it was known that both cuprous oxide and cupric oxide are produced, and part of this investigation has been directed towards obtaining data on the rate of cuprous oxide formation and to ascertaining whether different concentrations of oxygen affect film formation and stability under controlled laboratory conditions. The single crystals of copper used in this study were of cylindrical shape, about $\frac{1}{8}$ in. in diameter and 1 in. in length, with their axes parallel to the (110) crystallographic plane, permitting flat surfaces to be cut on the crystals parallel to the (110), (111), (100), and (311) planes. The specimens were mounted in such a way that, as films formed on the various crystallographic planes during the oxidation process, they could be measured with a polarizing spectrometer. This instrument, also called an ellipsometer, is capable of measuring thicknesses down to ± 3Å or even better by means of refractive-index techniques.

In preliminary tests, the specimen was immersed in a solution of oxygen and pure water in equilibrium with pure oxygen at a pressure of 1 atm. Comparative tests were then carried out with a 1% oxygen concentration, the total pressure being brought up to 1 atm by the addition of helium, followed by similar tests with 10% and 20% oxygen-helium atmospheres. From the results of these tests, it appears that, at low concentrations of oxygen, the cuprous oxide is the stable phase and that it grows to greater thicknesses than it does at high oxygen concentrations, when cupric oxide becomes the stable phase. In both high and low concentrations of oxygen, the (111) crystallographic plane exhibits the lowest rate of oxidation, possibly because it has the highest work function, i.e., it gives up its electrons less readily than all the other planes in the face-centred cubic space lattice of copper.

From *NBS Technical News Bulletin*, U.S.A., August 1961, pp. 134–135.

Readers desiring further information on any developments reported in THE BLUE PAGES are invited to write to the Editor. Copies of the full specifications of any British patents mentioned, which are published by courtesy of H.M. Stationery Office, should be obtained from the Patent Office, 25 Southampton Buildings, Chancery Lane, London, W.C.2. Price 3s. 6d. each.

● *IMPROVED UTILIZATION OF THE EXHAUST ENERGY OF DIESEL ENGINES*

Many reciprocating internal-combustion engines, particularly multi-cylinder diesel engines, use exhaust-driven turbo-superchargers, and various methods are employed to improve the utilization of the exhaust energy of these engines. In practice, however, it has been found that none of these measures has essentially resulted in a contribution to improving the transformation of exhaust energy into mechanical work.

To overcome the inherent drawbacks of existing methods, a new method of utilizing exhaust energy has been devised, in which, instead of the usual exhaust piping, an ejector device, comprising a nozzle, an ejector chamber, and a diffuser, is connected to each exhaust port. The nozzle communicates directly with the exhaust port of the cylinder, while the diffuser discharges, at its larger end, directly into a pipe or manifold for conducting the exhaust gases of all the engine cylinders to a turbine, which drives a rotary blower for supplying the necessary air for scavenging and charging. The outlets of the ejector into the manifold are each provided with a non-return flap-valve, and the chambers of the ejector are connected to each other by a pipe to the exhaust pipe of the turbine. After the exhaust valve opens, an exhaust wave flows through the exhaust port of the cylinder directly into ths nozzle of the ejector. The high velocity of the gas discharged from the nozzle reduces the pressure in the ejector chamber, and part of the exhaust gases is drawn from the turbine exhaust pipe. The ejector transforms the kinetic energy of the exhaust gases into pressure, and these gases, volumetrically augmented by the quantity drawn from the turbine exhaust pipe, are compressed in the manifold. When the gas pressure at the end of the diffuser falls below that of the manifold, the non-return flap-valve closes automatically, preventing gas from flowing back into the ejector.

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A process of controlled working which
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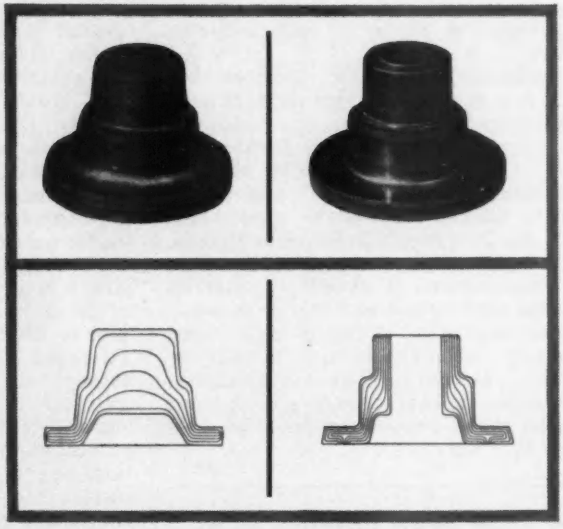
UP TO 95 % MATERIAL USAGE

An unusually high proportion of the initial blank is usefully employed and close tolerances can be held. Economic advantage over other methods results from material savings and decreased machining costs.

The heavy cold working imparts the strength of a heat treated steel to low carbon steel whilst the excellent grain flow closely following the finished contour, and the smooth surface finish, show to marked advantage under conditions of fatigue.

Forgings and Presswork Ltd are now equipped to produce a wide range of cold extruded steel parts and would welcome the opportunity to apply their specialized knowledge to *your* products.

The Motor Car Propeller Shaft Flange shown (left), was formerly made from Heat Treated EN8 steel. It is now produced from low carbon steel whose properties after extrusion (right) are equal to those of the EN8.



The pattern of flow lines in the extrusion (right) follows the external contour closely and is superior even to that of a forging where generous machining allowances are usual and really deep piercing is impossible.

Member of the Birfield Group

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As a result of the additional quantity of exhaust gases drawn by the ejector from the turbine exhaust pipe, a depression is caused in the engine exhaust system (without, however, reducing its energy content), and a more perfect utilization of the exhaust pressure waves is obtained by their transformation into a more constant pressure level. At the same time, the suction effect of the ejector reduces the back pressure behind the exhaust valves, thereby reducing the work required by the pistons to drive the gases out of the cylinders and hence to increase the efficiency of the working cycle.

From *Brit. Pat. Spec.* 876,957.
Ceskoslovenske Zavody Naftovych Motoru, Prague.

● *PRESSURE-COMPENSATED DEFORMATION GAUGES*

Designed to overcome the problem of measuring small changes in length in relatively inaccessible situations or in vessels containing liquids or gases, a new pressure-compensated deformation gauge is stated to be of simple and robust construction, to provide easy readings at any distance, with a total measuring range of about 10 mm and readings down to 0·001 mm, to have high resistance to humidity and temperature changes, and to be suitable for use under high static pressures in gases or liquids.

Operating on the principle of electric resistance strain gauges, the new gauge has a carrier element in the form of a simple deformation ring, rigidly connected to the gauge housing at one point on its circumference, with a feeler pin attached at its opposite point and projecting outwards through an accurately lapped bore in the housing. As the ring has to permit a considerable degree of deformation, it is flexible and very thin. It is therefore fitted with a restoring spring, which serves at the same time to counteract any friction between the feeler pin and the bore in the housing. The gauge, which has no bearings or joints, is rendered insensitive to small fluctuations in temperature by means of a compensating strain-gauge type of pick-up fitted on the side of the ring opposite to the measuring strain gauge and therefore operating in the same temperature zone. This arrangement can also be used, with the appropriate electrical connections, to double the sensitivity of reading. The housing is entirely filled with oil, and the gauge is sealed by a plastic membrane protected by a perforated cover. As a result, the pressure in the interior of the gauge is always equal to the static pressure outside, and there is no deformation of the housing at high pressures.

The finished gauges are calibrated once only on special equipment and are then given a constant calibration factor, changes in resistance multiplied by the calibration factor giving changes in length directly on a scale calibrated, for instance, in millimetres. Readings can be taken with any Wheatstone bridge, optimum results being obtained with d.c. bridges, which make it unnecessary to allow for wire quality and length. The leads from the Wheatstone bridge are soldered to readily accessible lugs on the outside of the gauge.

From *Sulzer Technical Review*, Switzerland, No. 1, 1961, pp. 37–38.

● *DYNAMIC HARDNESS-TESTING METHOD FOR GRINDING WHEELS*

Determination of the hardness of new grinding wheels is generally effected by static tests, none of which takes into account all the elastic factors so important to wheel performance. It is now reported, however, that a new dynamic hardness-testing method has been evolved which not only takes into account elastic factors, but also results in a considerable saving of time and labour. In addition, it is stated that it provides a more reliable evaluation of wheel hardness.

In the dynamic hardness-testing method, the wheel is mounted on the spindle of a lathe, and a conical cutter is drawn across the face of the wheel under test. The spindle of the cutter is mounted on a two-component lathe dynamometer fastened to the lathe cross-slide, the dynamometer measuring forces both vertically and horizontally. For testing, the cross-slide is set for the desired depth, and the cutter is fed across the wheel in either direction, crushing or cutting the wheel face. The surface velocities of the cutter and grinding wheel are the same, the wheel speeds being comparable with those used in production. During testing, the signal from the dynamometer is electronically amplified and is automatically recorded as an ink trace on a strip of graph paper, the trace (which can be read directly in pounds) being a record of the crushing force. With a hard wheel, the crushing force is high; with a soft wheel, tested under the same conditions, the crushing force is low. The force recorded on the graph can be interpreted as being made up of three components, i.e., a crushing component, an elastic component, and a packing component. The initial contact of the cutter with the grinding wheel under test is elastic. As the forces build up, the individual grains are split or are broken away from the bond, the magnitude of the force being determined by the strength properties of the bond and the number of grains in the zone of contact. The packing component, which is essentially elastic, is confined to the crushing zone and normally has little practical significance.

It is stated that a series of tests has indicated the feasibility of establishing industrial standards for grinding-wheel hardness by means of the new

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method. It also appears that it may result in developing a basis for predicting chatter conditions in grinding operations, and that it can give information regarding the effect of machine rigidity on grinding behaviour. In addition, it should be useful for predicting differences in performance of the same wheel on different grinding machines and under different grinding conditions.

From *The Tool and Manufacturing Engineer*, U.S.A., October 1961, pp. 83–86.

● *SUPERCONDUCTING MAGNETS*

Utilizing the principle of superconductivity at temperatures near absolute zero, a new magnet is about the size of a doughnut and weighs 1 lb, but creates a magnetic field twice as strong as that from a conventional iron-core electromagnet weighing 20 tons and requiring 100 kW of power to operate. By contrast, the new magnet requires the use of an ordinary motor-car storage battery for supplying continuously only the few watts of power needed to overcome the small losses incurred by the wires leading to it. Stated to be the first of its kind, the new magnet is believed to enhance considerably the possibility of direct, large-scale generation of electrical power, as well as the development of more powerful atom-smashers and of a magnetic "bottle" for enabling the energy of the hydrogen-bomb reaction to be harnessed for useful power.

The magnet contains about 2700 ft of wire, 0·01 in. in diameter, made from an alloy of the superconducting metals niobium and zirconium, about 5000 turns of the wire being wound into a coil, 2 in. in diameter and 1½ in. in length, with a central hole of ½-in. diameter. The coil, immersed in a vessel of liquid helium, is kept at a temperature of about −450°F, the energy required to cool the coil being only a small fraction of that needed to create a comparable magnetic field with a conventional electromagnet. Despite its small diameter, the wire can carry a current up to 20 A and, as distinct from iron-core magnets, which begin to saturate at a flux density of about 20,000 gauss, the superconducting magnet has a flux density of 43,000 gauss. In this connection, it is stated that some available superconducting materials have even better magnetic properties than niobium-zirconium alloys, but are at present more difficult to process in the form of fine wire, owing to their even greater brittleness. In any case, all superconducting materials of this type require extremely careful processing if their superconducting properties are to be preserved, and for these reasons the metallurgy of the most promising of these materials is being investigated.

From *Westinghouse Electric Corporation*, U.S.A., October 1961.

● *IMPROVED METHOD OF COATING METALS WITH PHOSPHATES*

Conventional methods of coating metals with phosphates usually suffer from the disadvantage that the coatings produced tend to have a coarse crystalline structure and to flake off comparatively easily. Also, attempts to produce finer crystalline layers by the addition of dehydrated phosphates to the phosphatizing solution are generally unsatisfactory, inasmuch as the hot acid solution tends to break down these phosphates, so that their grain-refining effects are diminished or entirely lost.

It is now reported, however, that these disadvantages can be largely overcome, so that extremely thin and adherent finely crystalline phosphate layers can be produced on metals, especially iron and steel, by the addition of one or more salts of organic quaternary ammonium bases formed with strong inorganic acids, such as hydrochloric acid, hydrobromic acid, and sulphurous acid, to conventional phosphatizing solutions. These organic quaternary ammonium bases can be of many different kinds, in which the organic radicals are alipathic, aromatic, hydro-aromatic, cyclo-alipathic, or heterocyclic, and preferably contain at least 18 carbon atoms, typical examples of their salts being alkyl-trimethyl-ammonium chloride, di-isobutyl phenoxy - ethoxy - ethyl - dimethyl - benzyl - ammonium chloride, and hexadecyl-hydroxy methyl-trimethyl-ammonium chloride. Only small amounts of these salts need be added to the conventional phosphatizing solution, which may or may not contain the usual wetting agents and accelerators, the amount of salt added usually lying between 0·1 and 10 gm/litre, and preferably between 0·3 and 2 gm/litre. In general, the more salt is added, the finer is the resulting grain structure. In fact, it is possible in this way to produce phosphate layers which are so thin and finely crystalline that they can hardly be perceived by the naked eye.

From *Brit. Pat. Spec.* 875,972. Gerhard Collardin G.m.b.H., Cologne, Germany.

● *TEST TRANSMISSION LINE FOR 750 kV*

To mark the start of a five-year American research and test programme to develop the information and experience necessary to transmit large blocks of power at voltages up to 750 kV, i.e., more than twice the operating voltage of present commercial systems in the U.S.A., a high-voltage test transmission line has recently been constructed, its main objective being to obtain data on the corona-loss and radio-influence performance of conductors at a nominal voltage of 750 kV. All tests will be completely instrumented, using magnetic-tape data-logging equipment, and the effects of various atmospheric conditions will be assimi-

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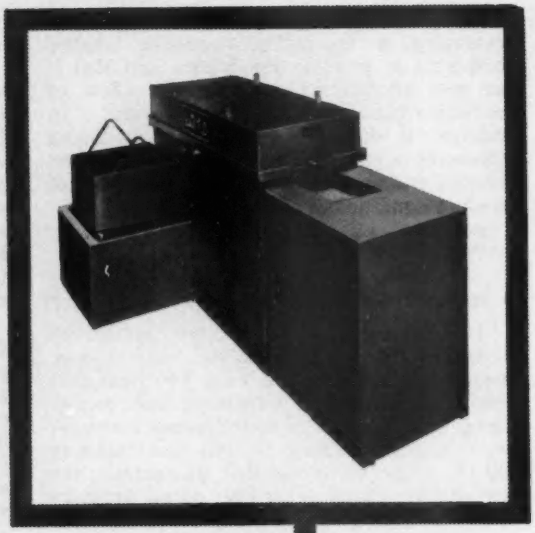

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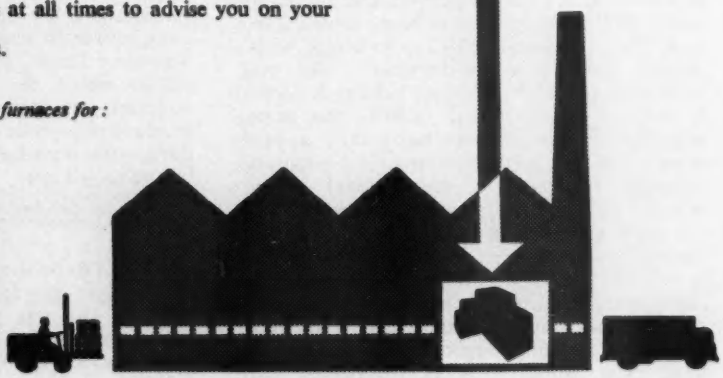

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lated into data for proper statistical analysis. In addition to corona loss and radio influence, readings will include temperature, relative humidity, air pressure, wind direction and velocity, and air contamination.

The test site is laid out in such a way that power passes from a 138-kV tap through a disconnect switch to a 138/750-kV auto-transformer, and then to a 750-kV bus structure. Three three-phase lines, 2400 ft in length, originate at the substation bus, forming a T-shape. A control and instrument house is located in the 138-kV switchyard near the load-break switch and auto-transformer. Calculations to select the optimum conductor size for 750-kV operation were based on experience obtained from other high-voltage projects. The three-phase lines use bundled conductors consisting of four separate conductors in 18-in. centres for each phase. Simultaneous independent radio-influence readings can be taken on each of the three lines, decouplers or blocking filters for radio-interference frequencies, installed between the lines, minimizing the interaction of radio noise. To prevent condensation on the line, it is necessary to keep the conductor slightly above ambient temperature and, to produce current for this heating, the four conductors in each phase bundle are insulated from each other and are connected in series. This arrangement keeps the conductors warm, as in normal use, with a minimum drain on the power system. The heating current circulated is equivalent to a load of about 1000 MVA on each line.

From *Mechanical Engineering*, U.S.A., October 1961, p. 66.

● *CONVERSION OF SONIC INTO LUMINOUS EFFECTS*

Various methods of converting sonic effects into luminous effects have been proposed, using, for instance, resonating quartz plates or piezo-electric plates. These methods have, however, certain inherent drawbacks, such as size limitations in the case of resonating quartz plates and relatively complex and costly construction in the case of piezo-electric plates. To overcome these disadvantages, a new method of converting sonic into luminous effects has been developed, in which an electroluminescent layer is mounted between two electrically conducting layers, one of which comprises a transparent film of electrically conducting material applied to a sheet of glass. This film is coated with an electroluminescent layer, over which is applied a piece of silk gauze having, for instance, from 5 to 10 strands per centimetre. A thin sheet of aluminium foil is stretched tightly over the gauze, which acts as a spacer and effectively divides the surface of the foil into a number of discrete elements. Each element of the foil constitutes a diaphragm which vibrates under the influence of sound waves independently of the other elements and varies the capacitance between the two conducting layers, i.e., between the foil and the film on the plate.

In operation, when a potential difference of, say, 500 V is applied between the two conducting layers, no light will be emitted by the electroluminescent layer, except in those regions where the diaphragm is set vibrating by sound waves. The intensity of light emitted from each region will depend on that of the sound falling on the discrete element concerned, so that, when the electroluminescent layer is viewed through the glass plate, a luminous pattern, corresponding to the sound pattern on the foil, will be seen.

From *Brit. Pat. Spec.* 880,817.
Thorn Electrical Industries Ltd., London, England.

● *NON-EXPLOSIVE, RADIO-FREQUENCY METHOD OF BREAKING ROCK*

Using radio-frequency electrical power, a new non-explosive method of breaking up rock has been developed and is stated to be about 5 times more economical than secondary breaking with explosives in underground mining, and up to 25 times more economical than secondary blasting in open-cast mining, earth-moving operations, and primary crushing of ores or raw materials. The process is simple, dustless, and requires only routine safety precautions, without the need to evacuate personnel, as distinct from standard explosive techniques, which require drilling, loading of explosives, and evacuation of workers.

In the new process, known as electrothermal forcing, electrodes are clamped to the rock and are connected to a source of high-energy radio-frequency power, creating a current-conducting path through the water trapped in the crystalline structure of the rock and comprising up to 5% of its bulk. Once established, this channel greatly decreases the internal resistivity of the rock, making it possible to pass the power through the rock between the electrodes. The resulting thermal stress is sufficient to split the rock along the path of conductivity. Although less force is required to break metal-bearing ores because of their lower initial resistance, the process can also be used successfully with hard rock such as granite and with rock materials normally considered non-conductive. Breaking up of the rock can be accomplished in times ranging from a few seconds to a few minutes, depending on the size of the rock and the method of applying power, and the forces applied can be controlled, as desired, to crack, break into chunks, or even to shatter the rock.

From *The General Electric Company*, U.S.A., October 1961.

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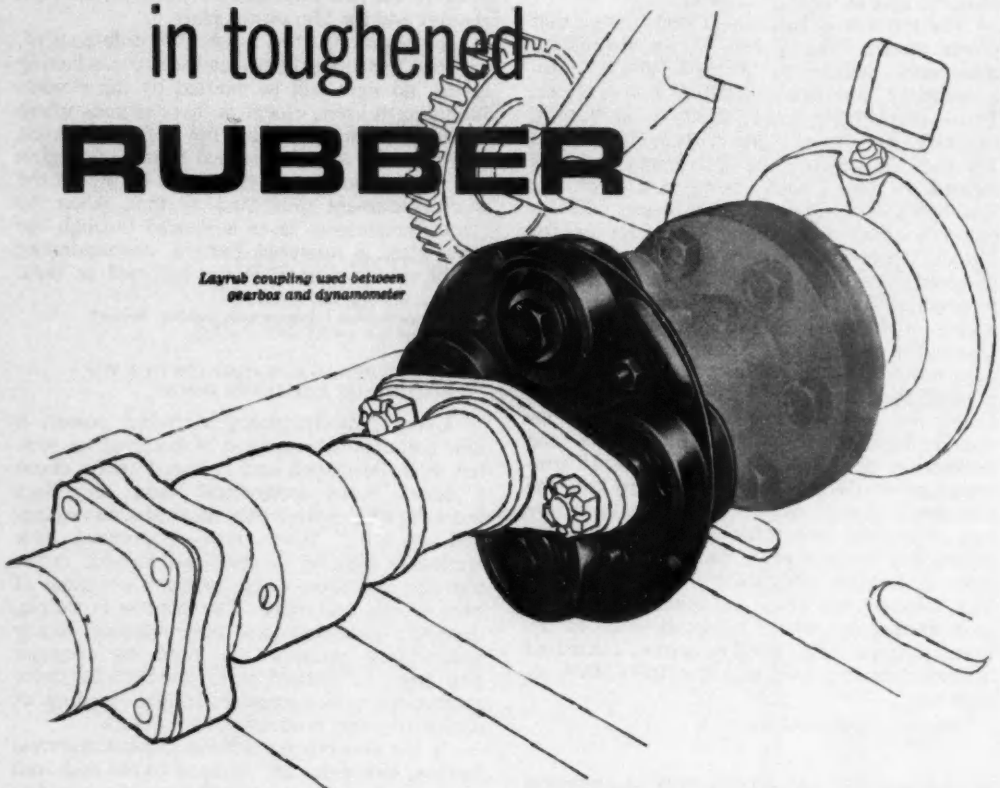

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Electrical and Metallurgical Factors Affecting Welding-Arc Stability

By J. E. GINN

From *Welding Journal*, U.S.A.,
Vol. 40, No. 9, September 1961,
pp. 942-946, 10 illustrations.

FOR weldments in which high quality and precisely controlled contour are of paramount importance, inert-gas-shielded tungsten-arc welding is an almost ideal joining process. However, although automatic voltage control affords precise and consistent results, arc instability or "arc blow" can repeatedly upset the inherently smooth and reliable operation of the system.

The automatic control of tungsten-arc welding, as well as the fused-metal geometry, is dependent on an arc which provides a stable conducting medium. Arc length is controlled by measuring the potential drop between the electrode holder and the workpiece, melting occurring at a point which is the shortest electrical distance from the electrode. Where thin-gauge materials (0·01 to 0·15 in.) are involved and where high quality is required, arc blow can be considered synonymous with failure. For this reason, and based on the elimination of erratic arc operation in the production welding of missile components by the inert-gas-shielded tungsten-arc process, an investigation has been carried out to determine the primary causes of arc instability and to derive methods of forestalling it. This investigation was directed towards providing a practicable manufacturing process, rather than attempting a theoretical explanation of the phenomenon. All work was effected with available direct-current straight-polarity equipment, and tests were conducted on low-carbon alloy steel and on stainless steel, as most problems had arisen with these materials.

A review of information concerning past arc-blow problems revealed that arc instability occurred under unrelated conditions, three distinct problem areas being apparent, i.e., (a) the properties of the materials being joined, (b) tooling materials and fixturing configurations, and (c) field forces. The causes, effects, and control of each of these problems are discussed separately below.

Material Properties

To determine the influence of heat-affected areas on arc stability, the edges of plates (0·08-in. gauge) of a low-carbon alloy (4330 M) were spot-heated to 1000°F and air-cooled to ambient temperature. The heated areas were approximately 1½ in. in width and 1½ in. apart, and the plates were butted together so that the heated zones were opposite the unheated zones. It was found that, during welding, the arc was repelled by the heated zones. Surface resistance tests showed that the heated zones had an electrical resistance of about 5000 micro-ohms, as compared with 500 micro-ohms for the unheated zones. Similar parts which had been grit-blasted or pickled did not deflect the arc, indicating that the electrical and thermal resistance of the surface oxide is a source of arc instability.

To determine the effects of work-hardening, an unbalanced condition involving work-hardened and annealed steel was created by arranging patches of 50% hydrospun-reduced material alternately with annealed patches, the parts being cleaned with methyl ethyl ketone. It was found that the welding arc was deflected towards the hydrospun patches. However, with hydrospun parts which had been pickled in hydrochloric acid and with annealed parts which had been pickled in nitric-hydrofluoric acid, the arc was not affected, indicating once again that the surface condition was the factor influencing arc operation.

Tests were also conducted on the effects of thermal hardening by heating alternate portions of the steel plates to 1500°F and quenching. This treatment yielded a hardness of Rockwell C50 on the heated portions, as compared with C18 for the unheated portions. The surface oxides were removed prior to welding, and it was found that the arc showed no indication of instability.

To ascertain the effects of mill scale, portions of the steel plate were reduced by 0·002 in. on each side by chemical milling, and the plate was then pickled in hydrochloric acid. It was found that, during welding, the arc was definitely attracted to the mill scale. Surface-resistance tests indicated that the chemically milled areas had a resistance of 35 micro-ohms, as compared with 80 micro-ohms for the pickled areas.

The results of these tests indicate that surface condition is the only material property of the low-carbon alloy steel which will cause an unstable welding-arc condition.

Tests on stainless steel were confined to 17-7 precipitation-hardened stainless-steel plates of 0·10 in. gauge, heated and welded in the same way as the low-carbon alloy steel. It was found that the welding arc was attracted to the oxidized areas of these plates, but that this instability occurred only on certain heats of the material, as other heats displayed a complete indifference to surface oxide. Analysis of the base metal indicated that the aluminium content had a bearing on this condition. Thus, two heats containing respectively 1·21 and 1·22% aluminium reacted to the oxide, while two other heats containing 1·11 and 1·14% aluminium were unaffected. If the higher aluminium content is the cause of the response, the question still arises as to why the arc deflected to the oxide, instead of to the pickled surface with its lower resistance (120 micro-ohms, as opposed to 5000 micro-ohms). The most striking difference in oxide composition was that the oxides attracting the arc respectively contained 21·5 and

25·3% chromium, while those not affecting the arc contained 5·3 and 17·8% chromium. It is possible that the conductivity of the affecting oxide increases at the elevated temperature present in the welding arc.

To determine the effects of grain structure and magnetic properties on arc stability, two of the stainless-steel plates were heated to 1400°F for 1½ hr and then cooled to 60°F, this treatment producing a martensitic structure with a hardness of Rockwell C35. Alternate areas of the plates were then annealed to a hardness of Rockwell C12, and all oxides were removed from the plates before welding. It was found that the arc was attracted to the martensitic structure, indicating that grain structure is a factor influencing arc stability.

During these tests, it became apparent that erratic arc operation resulted from the entrainment of a "slag" or oxide spot in the molten pool ahead of the electrode. As the oxide spot moved to one side, so also did the arc and the weld bead. In severe cases, the deflection of the arc was so great that lack of penetration resulted. Analysis of the oxide spot revealed a composition of 38% aluminium, 18% iron, and 2% tungsten, these being the only elements for which it was tested. Tests at elevated temperatures indicate that an oxide of such a composition may have less resistance than the molten steel at welding temperature. Problems occurred on heats of higher aluminium content, and it is this content which aggravates the arc-blow tendency with 17-7 precipitation-hardened stainless steel.

In an effort to improve arc stability, several commercial fluxes and several "concocted" formulae were applied to the weld joint. These preparations offered no marked improvement or advantage.

Tooling Materials and Fixturing Configurations

Probably the greatest source of arc-blow problems is failure to ensure that the parts to be welded are rigidly held in the immediate area through which the arc travels. It must also be appreciated that tooling which is designed and fabricated for particular applications sometimes lacks electrical continuity and will distort the field of the arc as the electrode passes along the welding joint.

Whenever practicable, non-ferrous materials, such as copper and aluminium, are used in that part of the tooling which is closest to the arc. When this application is not feasible, Type-301 stainless steel can be employed. Magnesium is finding an increasing use as a replacement for mild steel in primary fixture structure. All these materials are non-magnetic, because magnetic tooling has a great effect on the welding arc. Though this effect can be temporarily corrected by reverse polarizing, the chance of ruining assemblies makes magnetic tooling a most costly risk.

Tooling configuration is a greater source of trouble than tooling materials. As welded shapes have become more complex, the number of fixturing components contacting the welded assemblies have increased. This has led directly to the two tooling conditions which cause arc instability, i.e., field distortion caused by lack of contact with back-up support material, and field distortion caused by the air gap between the hold-down "shoes" or "fingers". Though these may seem to be obvious problems, their combined effects can be baffling. Proper design assures intimate contact, with back-up at all points, and minimizes air gap between fingers.

Heated tooling presents no particular problem if proper attention is given to the influence of the field. Infrared tubular lamps have been used in the welding development of steel pressure vessels without any discernible effect on the arc. Induction heating can also be successfully used with proper coil configuration and location (usually some distance in advance of the electrode).

Field Forces

It is sometimes impossible to avoid long arc lengths in automatic tungsten-arc welding because of an assembly procedure or the necessity of producing a particular bead configuration. In these situations, field effects are particularly apparent. The design geometry of parts being joined is seldom considered from a welding standpoint.

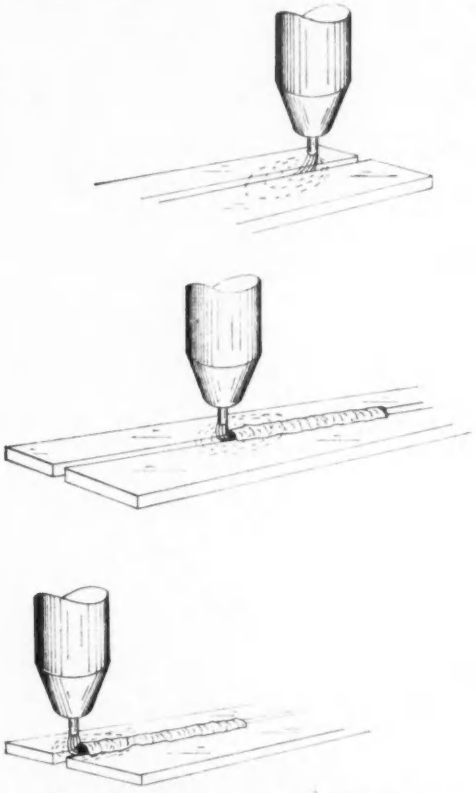

Fig. 1. Arc instability caused by field distortion.

Field-distortion tests indicate that the weld joint need not be pressed into contact, though it must be in close contact. Arc instability caused by field distortion is illustrated in Fig. 1, in which lack of field symmetry at the initiation of the weld results from lack of metal beyond the end of the plate, causing the arc to deflect forward. As the electrode progresses, the air gap in the plates, as opposed by the cast weld behind, causes greater reluctance in advance of the electrode; thus, the field is distorted and the arc deflects to the rear. At the end of the weld, lack of material at the end of the plate causes even more field distortion and a greater arc deflection to

(*Concluded on page 94*)

Tests on Cross-Flow Heat Exchangers with Tubes of Different Shapes

By H. BRAUER

From *Mitteilungen der Vereinigung der Grosskesselbesitzer (VGB)*, Germany, No. 73, August 1961, pp. 260-276, 30 illstrations.

IN heat-exchanger design, the endeavour is to obtain high heat flows with low energy losses for the flow media involved in the transfer of heat. The heat flow Q can be calculated from the relation

$$Q = hA\triangle T \quad .. \quad .. \quad .. \quad .. \quad (1)$$

where h is the heat-transfer coefficient, A is the heating surface, and $\triangle T$ is the temperature difference between the heating surface and the flow medium receiving heat.

The value of $\triangle T$ is to a large extent predetermined by the arrangement of the flow paths of the media transferring and receiving heat, and also by the permissible thermodynamic losses. By contrast, the heating (or cooling) surface A can be varied within wide limits by providing longitudinal or transverse ribs or fins. Ribbing, however, invariably results in a decrease of the heat-transfer coefficient h, so that the product hA will be greater with ribbing than without ribbing, though not in proportion to the corresponding increase in the heating surface.

The heat-transfer coefficient h for a specified flow medium can in most cases be increased only by altering the flow conditions Large heat-transfer coefficients are obtained with tubes in a transverse flow. However, heat exchangers of this type, consisting in most cases of tubes of circular section, produce very high energy losses, which have to be made up by means of pumps or blowers.

The power P required by these circulating units is calculated from

$$P = V\triangle p \quad .. \quad .. \quad .. \quad .. \quad (2)$$

where V is the flow volume of the circulated medium, and $\triangle p$ is the pressure loss of this medium in the heat exchanger. The pressure loss $\triangle p$ mainly depends on flow conditions, so that both pressure loss and heat transfer depend on the pattern of the flow, which is decisively affected by the shape of the tube cross-sections.

Flow Pattern and Heat Transfer for a Single Tube

Fig . 1 and 2 show flow patterns made visible by injecting a coloured liquid at ten equidistant points in the upstream end of two-dimensional models, almost all the energy loss of the flow being caused by the vortex trails. The vortex region behind the oval tube is much smaller than that behind the circular tube, so that it can be expected that an oval tube will cause lower losses.

The course followed by the streamlines impinging on the tube at the stagnation point is of considerable importance for the magnitude of the vortex region. As shown in Fig 1, these streamlines cling to the wall of the circular tube up to points just beyond the transverse tube diameter, and then separate from it. By displacing the separation points further down-stream, it is possible to reduce the size of the vortex region. This is achieved with the oval tube, as shown in Fig .2.

Displacements of the separation points, however, can also be caused by the state of the flow. With a circular tube, for instance, it is known that turbulent, instead of laminar, conditions delay flow separation, and also reduce the flow resistance to about 25% of its original value.

In a cross-flow heat exchanger, the magnitude of the vortex region is limited by the distance between consecutive tubes situated one behind the other. This tube arrangement also causes an earlier change from laminar to turbulent flow. Consequently, a bank of tubes of circular cross-section will have a lower flow resistance per tube than a single isolated tube under otherwise similar conditions. When oval tubes are arranged in banks, a comparable reduction cannot, however, be expected.

The heat transfer for a single circular tube will now be considered. In Fig. 3, the local Nusselt number $Nu = hL/k$ (where h is the heat-transfer coefficient, k is the thermal conductivity, and L is a characteristic dimension) is plotted as a function of the peripheral angle φ and Reynolds number Re. The Nusselt-number distributions are given in Fig. 3a for large Reynolds numbers, and in Fig. 3b for small Reynolds numbers. From Fig. 3a, it can be seen that the Nusselt numbers on the upstream side of the tube are substantially similar to those on the downstream side, except at extremely high Reynolds numbers. It is therefore immaterial whether the flow clings to the tube wall (as on the upstream side) or is in a turbulent condition (as on the downstream side). The important fact is that, for a good interchange of heat between the tube wall and the flowing medium, it is not

Fig. 1. Vortex trail behind a circular tube.

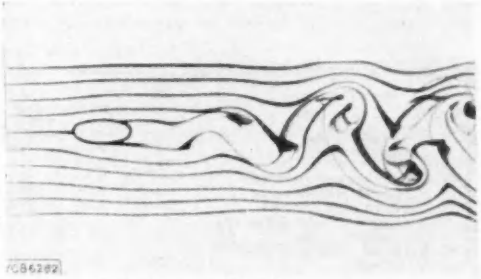

Fig. 2. Vortex trail behind an oval tube.

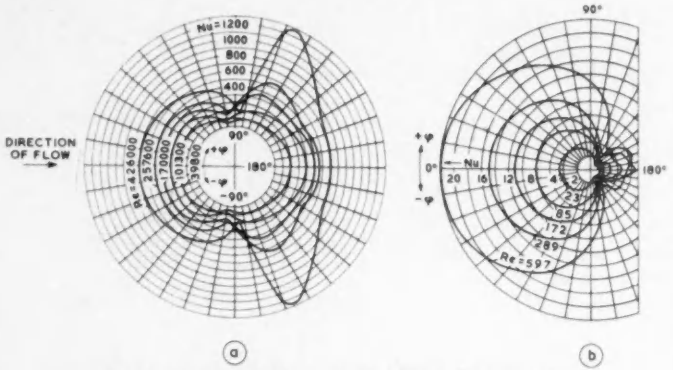

Fig. 3. Heat transfer for a circular tube in transverse flow.

necessary to have an extensive vortex region behind the tube, so that a limitation of the vortex region will not have an adverse effect on heat transfer.

The re-entrant (concave) portion of the curves in the vicinity of 90 deg. is due to flow separation. The transition to turbulent flow conditions at a Reynolds number of 426,000 gives rise to particularly high local values of Nusselt numbers behind the separation point. For low Reynolds numbers in the laminar-flow region, the heat transfer on the downstream side of the tube is, as shown in Fig. 3b, negligibly small in comparison with the transfer on the upstream side. However, conditions of this type hardly ever occur in tubular heat exchangers.

To sum up, the above considerations show that vortex trails, which are the main cause of flow resistance and energy losses, are not essential for good heat transfer. The effectiveness of heat transfer is mainly due to free flow on the upstream side. An advantage of oval tubes, therefore, is that they give just as good heat transfer as circular tubes, with less flow resistance. Bank of tubes give less flow resistance per tube and better heat-transfer conditions than a single tube, though these improvements are less marked with oval tubes.

Types of Heat Exchangers Investigated

Of the types of heat exchangers investigated, those with tubes of circular cross-section (Nos. 1, 2, and 3 in Table I) provided a basis for comparative assessments and enabled a study to be made of the effects of different longitudinal and transverse spacings. In all cases, a large number of rows was used, so as to have no appreciable effect on the test results. A typical arrangement of circular tubes is that shown for heat exchanger No. 3 in Fig. 4, in which the dotted lines indicate the narrowest free cross-sections of the flow, as required for calculating the maximum flow velocity in the heat exchanger.

The dimensions of the cross-section of the smooth profiled tubes used in heat exchangers Nos. 4 and 5 in Table I are shown in Fig. 5, and those of the fluted profile tube used in heat exchanger No. 6 in Fig. 6. Fig. 7 shows the dimensions of the finned tube used in heat exchanger No. 8, from which it will be seen that this tube has two tangential fins added to its circular centre portion.

Fig. 8 shows the arrangement of smooth profiled tubes in heat exchanger No. 4. The arrangement of the smooth profiled tubes in heat exchanger No. 5 was similar except that, because of its different spacings, it had only five rows of tubes in the direction of flow. Heat exchanger No. 6, with fluted tubes, had the same channel spacing as heat exchanger No. 5. Fig. 8 shows that, with the profiled tubes nearly touching each other at their outer ends, flow channels are formed with periodic

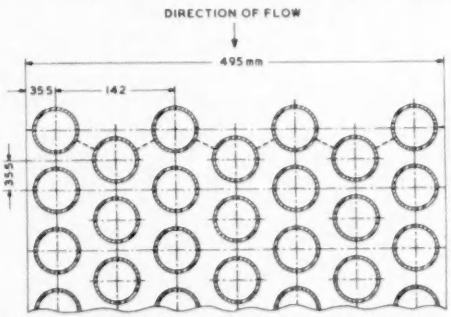

Fig. 4. Arrangement of circular tubes in heat exchanger No. 3

changes in width and direction, the object of these channels being to provide increased turbulence and greater heat transfer. Fig. 9 shows the composite arrangement of smooth profiled tubes and circular tubes used in heat exchanger No. 7, while Fig. 10 shows the composite arrangement of finned tubes and circular tubes used in heat exchanger No. 8. In the arrangements shown in Figs. 8, 9, and 10, the outer ends of the profiled tubes project into the vortex regions of neighbouring tubes and this, according to a French patent of A. Huet, should result in improved heat transfer.

Table I lists the main characteristics of the tubes in these heat exchangers in terms of their outer diameter d_o,

TABLE I: HEAT EXCHANGERS WITH CIRCULAR, PROFILED, AND FINNED TUBES

Heat Exchanger No.	Type	d_o [mm]	d_h [mm]	d_s [mm]	d_t [mm]	n_T	n_L	s_T [mm]	s_L [mm]	s_T/d_o	s_L/d_o
1	Circular tubes	42·0	42·0	42·0	33·5	6	6	140	70·0	3·33	1·67
2	Circular tubes	42·0	42·0	42·0	33·5	5	11	140	40·0	3·33	0·95
3	Circular tubes	54·0	54·0	54·0	49·0	7	10	142	35·5	2·63	0·66
4	Smooth profiled tubes	—	40·3	53·5	—	7	10	106	35·5	—	—
5	Smooth profiled tubes	—	40·3	53·5	—	7	5	97	35·5	—	—
6	Fluted profiled tubes	—	41·0	59·2	—	7	5	106	37·5	—	—
7	Smooth profiled tubes and circular tubes	—	40·3	53·5	—	7	12	97	35·5	—	—
8	Finned tubes and circular tubes	42·0	42·0	42·0	33·5	5	11	140	40·0	3·33	0·95

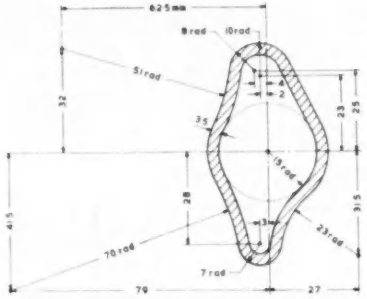

Fig. 5. Dimensions of the smooth profiled tubes used in heat exchangers Nos. 4 and 5.

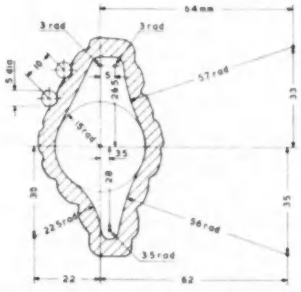

Fig. 6. Dimensions of the fluted profiled tubes used in heat exchanger No. 6.

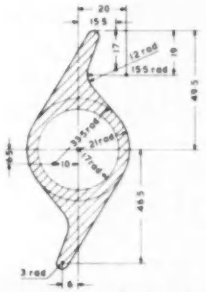

Fig. 7. Dimensions of the finned tubes used in heat exchange No. 8.

their inner diameter d_i, their equivalent hydraulic diameter d_h, their equivalent circular-tube diameter d_e, the number n_T of rows of tubes transverse to the direction of flow, the number n_L of row of tubes in the direction of flow, the transverse spacing s_T, and the longitudinal spacing s_L. To make it possible to assign a characteristic

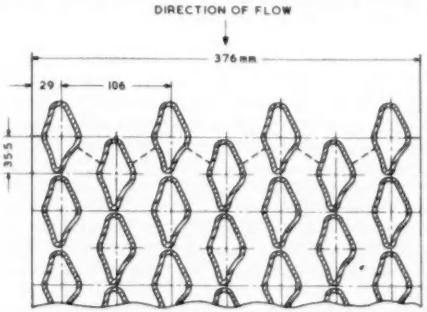

Fig. 8. Arrangement of smooth profiled tubes in heat exchanger No. 4.

dimension L to the profiled tubes for evaluations of Reynolds number $\mathrm{Re} = wL\rho/\eta$, where w is the flow velocity, η is the dynamic viscosity, and ρ is the mass density, the equivalent hydraulic diameters d_h were determined from the tube area A and perimeter s by means of the relation

$$d_h = 4A/s \qquad (3)$$

The equivalent circular-tube diameters d_e were also determined, using the relation

$$d_e = s/\pi \qquad (4)$$

For the finned tubes, however, the outer diameter d_o of the circular portion was used, this being 42 mm, as indicated in Table I. The values of d_e in Table I show that heat exchanger No. 4 with a smooth profiled tube was made from an initially circular tube with an outer diameter d_o of 53·5 mm. Consequently, the properties of this heat exchanger can be compared with those of the circular-tube heat exchanger No. 3. Similarly, the properties of heat exchanger No. 8 can be compared with those of heat exchangers Nos. 1 and 2.

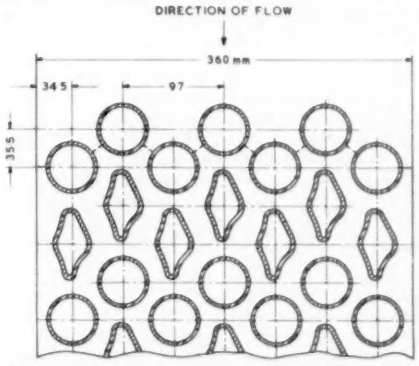

Fig. 9. Composite arrangement of smooth profiled tubes and circular tubes in heat exchanger No. 7.

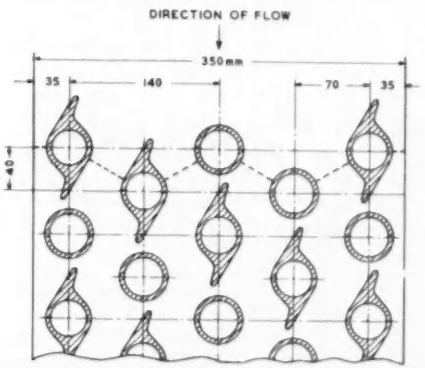

Fig. 10. Composite arrangement of finned tubes and circular tubes in heat exchanger No. 8.

TABLE II: HEAT EXCHANGERS WITH OVAL TUBES

No.	d_{max} [mm]	d_h [mm]	d_e [mm]	d_{min} [mm]	n_T	n_L	s_T [mm]	s_L [mm]	s_T/d_{min}	s_L/d_{max}
27	36	19·2	26·3	14	5	14	52	22	3·71	0·61
28	36	19·2	26·3	14	5	14	44	22	3·14	0·61
29	46	30·6	36·3	25	7	10	39	56	1·56	1·22
30	46	30·6	36·3	25	7	10	78	28	3·12	0·61
31	38	23.5	29·3	19	7	10	60	23	3·16	0·61

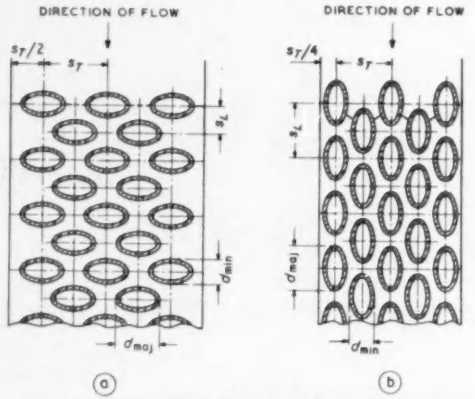

Fig. 11. Arrangement of oval tubes (a) in heat exchanger No. 27 with the minor axis of the tubes in the direction of flow, and (b) in heat exchangers Nos. 28, 30, and 31, with the major axis of the tubes in the direction of flow.

Tests were also conducted with heat exchangers having oval tubes, the major characteristics of these being listed in Table II. Fig. 11a shows the arrangement of tubes used in heat exchanger No. 27, in which the minor axis d_{min} of the tubes is in the direction of flow, while Fig. 11b show the arrangement of the tubes in heat exchanger No. 28, in which the major axis d_{maj} is in the direction of flow. The arrangement of tubes in heat exchanger No. 28, also used in heat exchangers Nos. 30 and 31, creates flow channels which permit only a limited amount of fluid to pass from one channel to the next. By contrast, heat exchanger No. 29, shown in Fig. 12, uses an arrangement of staggered tubes, designed to promote mixing of the fluid behind each row of tubes.

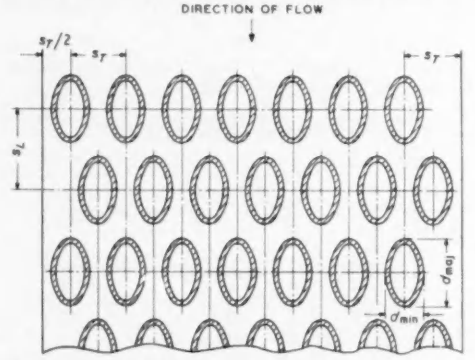

Fig. 12. Staggered arrangement of oval tubes used in heat exchanger No. 29.

Test Installation and Measuring Equipment

The test installation comprises an air-flow channel of the open-circuit type, shown schematically in Fig. 13. Air entering the inlet (1) flows into a transition section (2) and then passes through the heat exchanger (3) and the outflow section (4), after which it is drawn into a rectangular-section (400 × 355 mm) channel by means of a fan (5) and discharged. A hydraulic coupling (7) is interposed between the fan and its drive motor (6), in order to absorb any minor output fluctuations of the motor and hence to ensure smooth running of the fan and uniform air delivery. The fan has a nominal capacity of 18,000 m³/hr and produces a pressure differential of 700 mm of water.

The heat exchanger (3) is heated by steam fed through a supply pipe (9) into an expansion chamber (8) which ensures a uniform distribution of steam around the heat-exchanger tubes. After passing through the heat exchanger, the steam passes into a pyramid-shaped receiver (10), from which the condensate flows out through a passage (11) into a calibrated measuring vessel (12), the level of the condensate being indicated by a sight gauge (13). All the heated structural components are thermally insulated, and the condensate vessel is provided with a steam jacket (14) which is supplied with steam by a pipe (15) connected to the main steam supply (9). In this way, any condensate forming in the supply pipes can also be extracted before reaching the heat exchanger and the measuring vessel (12), ensuring accurate measurements at low air velocities. Coarse control of air flow is achieved by varying the quantity of hydraulic fluid in the coupling (7) so as to alter the fan speed. Fine adjustments are made by means of throttle valves (16) and (17), and by an additional air-intake.

During the tests, the air flow was determined by pressure measurements at a position immediately behind the inlet (1) by means of a micro-manometer (18). A similar unit (19) was used to determine the pressure loss of the air as it passed through the heat exchanger. Air temperatures before and after the heat exchanger were measured with thermometers (20) and (22). Because of the acceleration of the air flow in the nozzle (21), good mixing of the air was obtained, and the air temperature was therefore practically constant over the entire cross-section. Steam temperatures were checked with a thermometer (23). The heat taken from the steam was evaluated from the amount of condensate collected in the measuring vessel (12). As a check, the quantity of heat transferred was also evaluated from the measured air temperatures.

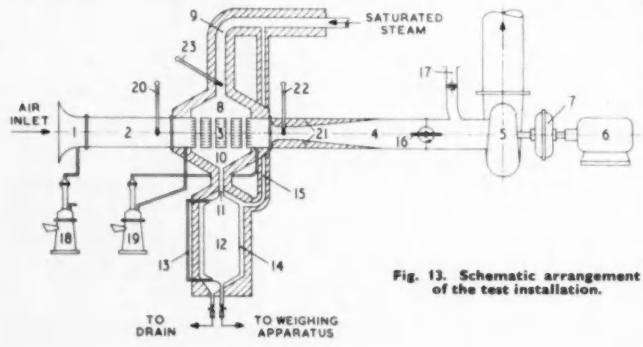

Fig. 13. Schematic arrangement of the test installation.

From the measured quantities, the heat-transfer coefficient was evaluated by means of eq. (1). The value of $\triangle T$ was determined as the logarithmic mean of the temperature difference between the tube wall and the air, taking the steam temperature T_{st} as a sufficient approximation for the wall

temperature, and using the relation

$$\Delta T = \frac{T_{out} - T_{in}}{\log_e [(T_{st} - T_{in})/(T_{st} - T_{out})]} \quad .. \quad (5)$$

where T_{in} and T_{out} are the respective air temperatures at the inlet and outlet cross-sections of the heat exchanger.

The value of the heat-transfer coefficient h was then related to the non-dimensional quantities governing heat transfer, i.e., the Nusselt number and Reynolds number, as previously defined, and also to the Prandtl number Pr, which is defined as

$$Pr = \eta_i c_p / k \quad .. \quad .. \quad .. \quad .. \quad (6)$$

where η_i is the dynamic viscosity, c_p is the specific heat, and k is the thermal conductivity. As previously stated, the outer diameter d_o was taken as the characteristic dimension L for circular tubes. For non-circular tubes, the evaluations were based on the equivalent hydraulic diameter d_h in eq. (3), the use of which has been justified theoretically[1].

The pressure loss Δp was also measured and represented by an equivalent non-dimensional resistance coefficient ψ, referred to one row of tubes and defined as

$$\psi = \Delta p / (\tfrac{1}{2}\rho w^2 / n_L) \quad .. \quad .. \quad .. \quad (7)$$

where n_L is the number of rows of tubes in the direction of flow. The coefficient of specific resistance ψ depends on the Reynolds number and on parameters associated with the geometrical arrangement, which will be considered in the test results.

(To be concluded)

The Determination of Losses in Electrical Machines by Calorimetric Methods

By W. Liebe

From *Elektrotechnische Zeitschrift* (*ETZ*), Germany, Part A, Vol. 82, No. 19, September 11, 1961, pp. 610-611, 2 illustrations.

The idea of determining the losses in electrical machines by calorimetric measurements was originally made some decades ago, and its technological features have been discussed in a number of papers. However, it is only in very recent years that the calorimetric method has been applied in practice[1,2,3].

As regards reliability and accuracy, the calorimetric method is quite equal to conventional methods of loss determination. In many cases, it is even superior to these methods, e.g., when the windage losses have to be determined separately. The calorimetric method is simple and has practical advantages, and enables measurements to be made, for instance, on a completely installed hydro-electric generator at the erection site, without removing the water from the turbine.

Calorimetric determinations with either air or water as the flow medium give fully equivalent results, as has been verified in practice. Consequently, calorimetric measurements of losses can be made both in the primary air circuit and in the secondary cooling-water circuit. This finding is important because of the prevailing opinion that accurate air measurements are too difficult with large machines. It has been possible, with the improved measuring procedures available, to provide evidence that calorimetric determinations based on air measurements also reach the degree of accuracy desired. It is therefore possible to use the calorimetric method in plants operating with a fresh-air supply, in which case only a calorimetric procedure using air measurements is applicable.

In order to assess the reliability of the calorimetric method, comparative measurements have been made on large hydro-electric generators, whose losses had already been determined by conventional measurements. Fig. 1 gives the results of such investigations[3]. In this diagram, the difference between loss measurements made by the calorimetric method and by conventional methods is plotted against actual values. The solid circles refer to air measurements, and the open circle and triangles to measurements obtained from the cooling-water flow. The deviation between calorimetric indications and conventionally obtained values is less than 2% of the actual losses, and it is difficult to say which of the two methods of measurement is more accurate. With regard to efficiency, a deviation of this size represents an error of less than 0·1% for efficiencies of the order of 97%. In the two tests denoted by triangles, only the electrical losses are compared. Owing to differences in the method of mounting the turbine for testing at the maker's works and the method of mounting at the actual erection site, the frictional losses determined in the test at the maker's works were apparently too high and therefore could not be used in these comparisons.

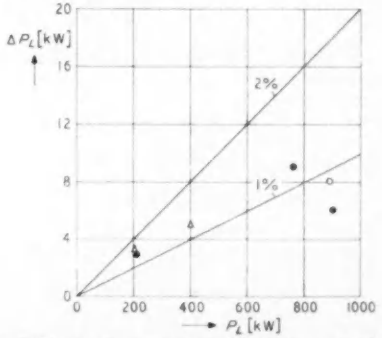

Fig. 1. Difference in power loss ΔP_L between calorimetric methods of testing and conventional methods of testing in terms of the actual power losses P_L of various sizes of hydro-electric generator.

The calorimetric method can provide measurements of individual losses, as well as measurements of total losses. Analyses of results from hydro-electric generators have shown that the sum of the individual losses deviates by less than 3% from the total losses measured under operating conditions. As it is frequently difficult to maintain the output of a machine constant during a total-loss measurement for the required measuring period of at least six hours, and the measurement of individual

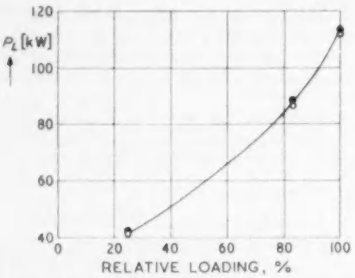

Fig. 2. Power loss P_L of an asynchronous motor, as determined at the erection site by calorimetric methods, in terms of relative loading.

losses also allows a closer assessment of relationships between various quantities, it is an advantage to measure individual losses in tests on this type of equipment.

The use of the calorimetric method will be necessary when assembly of the machine can take place only at the erection site or when a test at the maker's works would involve unacceptably high costs. This applies particularly to large hydro-electric generators for which evidence of efficiency figures is required. The method, however, will also be useful in other applications, such as tests on large asynchronous motors whose losses could not previously be determined accurately, either on the test bed or at the erection site.

Fig. 2 shows the results of such measurements on a large asynchronous motor, the total losses being determined calorimetrically with air (solid circles) and with water (open circles) for various load conditions. These tests are particularly interesting, because it was possible in this plant to obtain calorimetric results from both air and water measurements.

Special equipment has been developed for carrying out calorimetric measurements[3]. In addition to the flow rate Q [m³/sec] and the temperature rise ΔT of the coolant, which can be determined very accurately, it is also necessary to know the density ρ [kg/m³] of the cooling medium at the position of flow measurement, since the power loss P_L is obtained in terms of the heat transferred to the cooling medium from the relation

$$P_L = cQ\rho\,\Delta T$$

where c is the specific heat [watt-sec/kg°C] of the cooling medium, as taken from tables. If the cooling water contains air bubbles or other gases, the value of neither c nor ρ can be given accurately. The calorimetric measurement with water is then not applicable.

The calorimetric determination of the heat flow emanating from a machine does not include all the losses occurring in the machine, so that bearing losses (if the bearings are situated outside the machine or are liquid-cooled) and convection losses from the walls of the machine to the surrounding air must be determined separately. For the bearing losses, a calorimetric procedure can again be used[4]. The heat flow from the walls to the outside air gives an additional contribution, which is, however, comparatively small for large machines. This can be estimated if the casing surfaces involved, the wall-surface temperature, and the ambient-air temperature are known, by assuming a mean wall/air heat-transfer coefficient of about 10 W/m²-°C. For large machines, the quantity of heat flowing away through the foundations and the shaft of the machine is negligible.

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Transformer Bank with a Rating of 1000 MVA

By P. Hessen

From *ASEA Journal*, Sweden,
Vol. 34, No. 6, 1961,
pp. 102-106, 5 illustrations.

A remarkable transformer bank with a rating of 1000 MVA—as far as is known the highest at present in existence—has recently been manufactured by ASEA and installed in the Swedish 400-kV system. This transformer bank, the data of which are given below, consists of three single-phase units and one spare unit.

Rating:	1000/1000/333-MVA
Rated voltage:	400/217/20 kV
Connection:	Auto-star/delta
Frequency:	50 cps

Impedance voltages:

400 to 217 kV, u_{sc} = 8% on 1000-MVA base
400 to 20 kV, u_{sc} = 10·2% on 333-MVA base
217 to 20 kV, u_{sc} = 7·3% on 333-MVA base

Basic insulation levels:

400-kV winding: 1500-900 kV, graded insulation
217-kV winding: 900-375 kV, graded insulation
20-kV winding: 125 kV

Each single-phase unit:

Weight, including oil:	259 tons
Transport weight:	187 tons
Length:	37½ ft
Width:	16½ ft
Height:	30 ft

The transformers are designed for continuous operation at 110% rated voltage.

Transformer Core

To permit transport within the railway loading gauge, a five-limbed core design (Fig. 1) with windings on three limbs was adopted. This type of core has been used previously by ASEA for 400-kV transformers, but the detailed design of the core (built of cold-rolled grain-oriented steel) has changed considerably since the first transformers were supplied to the Swedish 400-kV system.

Transformer Windings

Both the 400-kV and the 217-kV windings are of the disc type, with all three limbs of each winding connected in parallel. The 20-kV windings are also identical on each

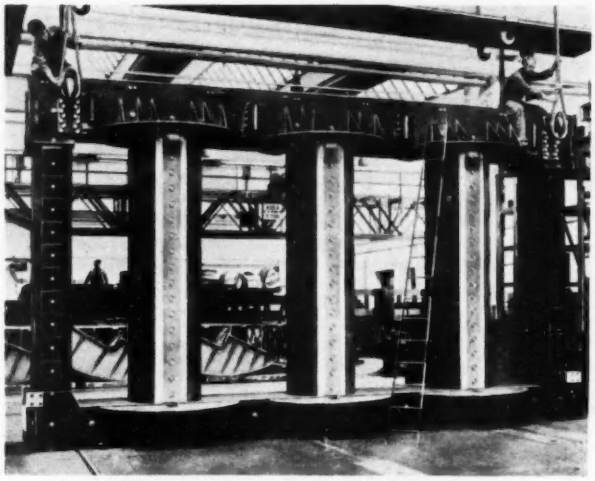

Fig. 1. Five-limb design of the 1000-MVA transformer bank.

limb. The 400-kV line entry is half-way up the limb. The 400-kV winding on each limb has two parallel-connected sections, thus permitting the same insulation level at the yokes as at the line end of the 217-kV winding.

The entrance coils are provided with the same type of electrostatic shielding ring as previously used for all transformers of this voltage manufactured by ASEA. In spite of the simplicity of design, this shielding arrangement gives a good voltage distribution in the windings, both between adjacent coils and to earth. The calculation of this voltage distribution for 0·02 μsec full and chopped waves no longer presents any major difficulties. The internal insulation between adjacent turns and coils in the windings is designed to match the actual voltage distribution with approximately the same factor of safety throughout the whole winding. Impulse tests and power-frequency tests have been successfully carried out on each unit.

Short-Circuit Strength

The transformers are designed to withstand safely the largest forces encountered under short-circuit conditions. Each winding is compressed by means of a series of drying, pressing, and impregnating processes to produce and maintain the correct height of the winding when the maximum pressure liable to occur under short-circuit conditions is applied. These preshrinking operations are carefully controlled, and experience has shown that windings checked during reconditioning after many years of service still maintain the same pressure when they are compressed to the same height.

The available short-circuit powers in the connected systems are governing factors in the design of transformers of this size. To illustrate this point, a simplified example is given here, in which the current fed in from the 20-kV side is neglected.

The impedance of 8% on a 1000-MVA base signifies a short-circuit current of 12·5 times the rated current with infinite short-circuit power in the system. However, if the available short-circuit power is limited to, for example, 15,000 MVA (equivalent to a system impedance of 6·7% on a 1000-MVA base), the short-circuit current is reduced to 6·8 times the rated current. The forces in the windings are thus reduced to about 30% of the previous value, indicating the important difference for these large transformers between infinite short-circuit power in the system and, for example, 15,000 MVA, which for smaller units may be considered as infinite without significantly influencing transformer design.

The calculation of the short-circuit and earth-fault currents in the windings is, of course, more complex than the above example would appear to indicate. However, since all three parallel-connected limbs have similar winding arrangements, a symmetrical distribution of the fault currents in the three limbs can be assumed. The transformers can therefore be treated as three-winding transformers.

The equivalent circuit for one phase based on measured values of the impedances is given in Fig. 2a, whereas the significance of the earthing conditions of the system is indicated by the equivalent circuit of the zero-sequence impedances for an earth fault on the 217-kV side shown in Fig. 2b.

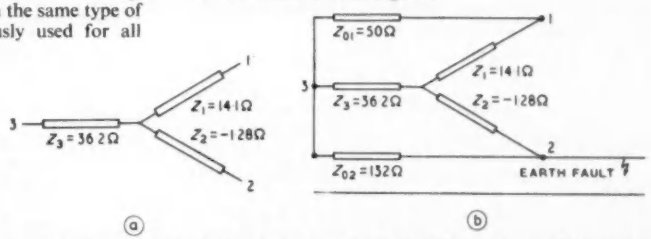

Fig. 2. Equivalent circuit for (a) short-circuit impedances and (b) zero-sequence impedances. Z_1, Z_2, and Z_3 are the impedances of the transformer bank referred to 400 kV, and Z_{01} and Z_{02} are the zero-sequence impedances of the system.
(1) 400-kV terminal (2) 217-kV terminal (3) 20-kV terminal

When calculating the earth-fault currents in the windings, the method of symmetrical components can be used. The equivalent diagrams for the positive and negative components then consist of Fig. 2a supplemented by the addition of the system impedances. A simple calculation shows that about 85% of the total earth-fault current has to pass the transformer windings.

Bushings

The bushings are among the largest ever manufactured for these high voltages, and the 400-kV, the 217-kV, and the neutral bushings are all of the draw-lead type. This allows mounting of the bushings without lowering the oil level in the transformer tank.

Cooling Equipment

Cooling is provided by ten forced-oil, air-blast heat-exchanger units for each single-phase transformer. Eight of these are mounted directly on the transformer, and two are set up separately. For each transformer, an air flow of approximately 4100 m³/min is required. The oil circulation of approximately 6000 litres/min for each unit is handled by five pumps. The cooling equipment is thermostatically controlled by the top-oil temperature in such a way that at any loading only the required number of coolers will be in service.

The Theory of Combined Steam- and Gas-Turbine Installations

(Concluded from October issue)

By C. Seippel and R. Bereuter

From *Brown Boveri Review*, Switzerland,
Vol. 47, No. 12, December 1960,
pp. 783-799, 8 illustrations.

Recuperation Efficiency:—

Owing to the linear relationship between the heat to be recuperated R and the gas temperature T, only the portion η_c is available to do work, i.e.,

$$\eta_c = \frac{1}{R}\int_{T_8}^{T_7}\left(1-\frac{T_0}{T}\right)\mathrm{d}R = 1 - \frac{\log_e T_7/T_8}{T_7 - T_8}\,T_0 \qquad (9)$$

In this equation, T_0 is the ambient temperature, i.e., that of the cooling water.

The heat must be transferred to a working medium such as a steam circuit, as indicated by the dotted lines in Fig. 4. The three sections of the line represent feed-heating, evaporation, and superheating. The useful part of the heat contained in the steam, i.e., the "cycle efficiency", is given by

$$\eta_{tPr} = \frac{\triangle h - T_0\,\triangle s}{\triangle h} \qquad (10)$$

where $\triangle h$ and $\triangle s$ represent the enthalpy and entropy absorbed by the steam generator. Since the temperature T' in the steam circuit is lower than T in the gas, $\eta_{tPr} < \eta_c$.

The usable energy in the steam is utilized at the "thermodynamic" efficiency of the turbine η_{td}, which takes into account the losses in the turbine and generator, the power used to drive the feed pump, and the irreversibility of the feed-heating system and condenser. Hence,

$$\eta_{tR} = \eta_{tPr}\eta_{td} \qquad (11)$$

When the recuperated heat is transferred to the feedwater, as in schemes C and D in Fig. 1, the output of the turbine, can be equated to the two amounts of heat applied to the circuit per second, i.e., $V = V' + V''$ and R. Thus,

$$P = \eta_{th}(V' + V'') + \eta_{tR}R$$

where R is the recuperated power from the exhaust-gas temperature to the temperature corresponding to the highest bleed point, and V'' is the power recuperated above the temperature determined by the highest bleed point. Hence V'' is applied to the whole of the feedwater and can thus be added to the boiler.

$\eta_{tR}R$ can be determined as follows:— T_7, T_8, T_7', and T_8' (Fig. 6) are stipulated, T_8 being the given final temperature of the gas and T_7' the given final temperature of the feedwater; T_7 and T_8' are given by the selected temperature differences of the preheater. Then R and the ratio of the division of the feedwater have to be determined, and the bleeding quantities taken from the thermal diagram of the turbine, in particular those quantities which would have been required to heat the diverted feedwater. The gain in output resulting from its remaining in the turbine can also be determined from the thermal diagram.

Gas-Turbine Output and Choice of Working Pressure:—

The compression and expansion powers C and E per kg/sec of air are calculated with the aid of the following equations, the suffixes 0 and 1 referring to the stagnation conditions before and after the compressor blading, and 3 and 4 before and after the turbine blading (diagrams C and D).

$$C = c_{pc}(T_1 - T_0) \qquad (12)$$

$$T_1 = T_0\pi^{a_c} \qquad (12a)$$

where $\pi \equiv p_1/p_0$ is the compression ratio,

$$a_c \equiv \left[\frac{\mathrm{R}}{c_p}\right]_c \frac{1}{\eta_{ic}} \qquad (12b)$$

is the polytropic exponent of the compression and

η_{ic} = polytropic efficiency of the compressor blading

R = gas constant

$$E = \frac{m_E}{m_c}\,c_{pE}(T_3 - T_4) \qquad (13)$$

$$T_4 = T_3(\varepsilon\pi)^{-a_E} \qquad (13a)$$

where $\varepsilon\pi = p_3/p_4$, the pressure ratio on expansion

$$\varepsilon = \Pi(1 - \delta p/p)$$

or $\log_e\varepsilon = -\Sigma\,\delta p/p$, in which $\Sigma\delta p/p$ is the sum of all pressure-drop ratios in the inlet and outlet pipes of the machines, piping, combustion chambers, heat exchangers, and, under the appropriate conditions, less the resistance on the gas side of the boiler.

$$a_E = \left[\frac{\mathrm{R}}{c_p}\right]_E \eta_{iE} \qquad (13b)$$

is the polytropic exponent of expansion,

η_{iE} = polytropic efficiency of the turbine blading and

m_c, m_E = mass flows through compressor and turbine, respectively.

With the aid of eq. (5), an attempt will now be made to obtain the compression ratio π which yields the maximum power gain and, because of the constant heat input, the maximum efficiency. Differentiating eq. (5) and equating to zero leads to

$$\mathrm{d}(P - P_0) = \mathrm{d}[(\eta_{el} - \eta_{th})(E - C) - (\eta_{th} - \eta_R)R] = 0$$

In this equation, R is variable if the energy is fed into an independent steam circuit, and also if the gas temperature at the inlet to the recuperator is governed by a preceding flue-gas air heater, the latter influencing the choice of the bleed points. In contrast, R is constant when the gas temperature is prescribed only by the final temperature of the feedwater (schemes E and F). On this assumption $\mathrm{d}(E - C) = 0$.

The most favourable case is a gas turbine with the maximum output per kg of air per second, and not a turbine with maximum efficiency. From eqs. (12) and (13),

$$\mathrm{d}(E - C) = -c_{pc}\mathrm{d}T_1 - \frac{m_E}{m_c}\,c_{pE}\,\mathrm{d}T_4 =$$

$$= - c_{pc}\, a_c\, T_1 \frac{d\pi}{\pi} + \frac{m_E}{m_c}\, c_{pE}\, a_E\, T_4 \frac{d\pi}{\pi} = 0$$

or with

$$\eta_G \equiv \frac{m_E}{m_c}\,\frac{c_{pE}}{c_{pc}}\,\frac{a_E}{a_c} = \frac{m_E}{m_c}\,\frac{R_E}{R_c}\,\eta_c\,\eta_E$$

$$T_1 = \eta_G\, T_4 \qquad .. \quad .. \quad .. \quad .. \qquad (14)$$

Since the inlet temperatures T_0 and T_3 are generally given, it is possible, with the aid of eqs. (12a) and (13a) to write

$$\pi^{(a_c + a_E)} = \frac{\eta_G\, T_3}{\varepsilon^{a_E}\, T_0} \qquad .. \quad .. \quad .. \qquad (15)$$

If, on the other hand, R is variable, then η_R will also be variable. It is convenient to introduce the marginal value $\eta_{R,\,mg}$ of η_R, which originates from the degree of utilization of the last element of input heat dR. This occurs at the highest temperature T_7. Hence, its Carnot fraction is $1 - T_0/T_7$, so that, to a first approximation $\eta_{R,\,mg}$ and η_R may be substituted in this proportion. According to the definition of the marginal efficiency

$$d\,(\eta_R R) \equiv \eta_{R,\,mg}\, dR$$

Since $R = C$, $dR = dC$ while, according to eqs. (14) and (15)

$$T_1 = \left(\frac{\eta_{el} - \eta_{th}}{\eta_{el} - \eta_{R,\,mg}}\right) \eta_G\, T_4 \qquad .. \quad .. \qquad (14a)$$

$$\pi^{(a_c + a_E)} = \left(\frac{\eta_{el} - \eta_{th}}{\eta_{el} - \eta_{R,\,mg}}\right) \frac{\eta_G}{\varepsilon^{a_E}} \frac{T_3}{T_0} \qquad .. \qquad (15a)$$

When evaluating this equation, it must be borne in mind that π is implicitly included in $\eta_{R,\,mg}$.

In the realization of an installation it is, of course, not necessary to adhere strictly to the optimum working pressure. The price and controllability of the machines may give rise to modifications which, provided they are not unduly large, only cause quite small, and therefore permissible, drops in the efficiency. However, the efficiency at optimum pressure should always be regarded as a measure of what can be attained.

Gas Turbines with Heat Recovery

Considering first a gas turbine without any subsequent combustion, as shown in diagram G of Fig. 1 the previous stipulation that fuel input must be constant can in this case be discarded.

If, in eq. (2), both V and H_2 are assumed to be zero, it can be stated that $\eta_H H_1 - Z - (E - C) - R = 0$ or, with $R = C - (Z - \Delta)$ (see eq. (7)), $\eta_H H_1 = E + \Delta$. The output is then

$$P_1 = \eta_{el}\,(E - C) + \eta_R R - P_{aux}$$

and the efficiency is

$$\eta_{GT} = \frac{P_1}{H_1} = \frac{\eta_{el}\,(E - C) + \eta_R R - P_{aux}}{(E + \Delta)/\eta_H}$$

In the second combustion chamber (diagram B), the fuel energy H_2 which can be increased from 0 to $H_0 - H_1$ is added. In the steam turbine, an additional amount of energy $\eta_{th}\eta_H H_2$ is produced. At the same time, the final air-heating temperature can be changed and the ratio of the first to the second fuel input shifted, without changing the efficiency of the installation. This might be necessary if the gas temperature in the high-pressure boiler were not sufficiently high to realize the desired steam cycle. It must then be remembered that, in subsequent equations, H_1 and H_2 are no longer the fuel heat inputs to the combustion chambers, but that H_1 is the heat needed by the gas-turbine cycle alone, and H_2 the surplus above it.

The efficiency of the combined installation—with variable amounts of excess air—is given by

$$\eta - \eta_{GT} = (\eta_{th}\,\eta_H - \eta_{GT})\,\frac{H_2}{H} \qquad .. \qquad (17)$$

the H_2 part of the steam plant only being advantageous if $\eta_{th}\eta_H > \eta_{GT}$, in which case eq. (17) shows that H_2 must be made as large as possible. This implies that, as for the plain steam cycle, an effort should be made to execute combustion with the smallest possible amount of excess air, so that the previous stipulation $H_1 + H_2 = H_0$ is justified. If, on the other hand, $\eta_{th}\eta_H$ is smaller than η_{GT}, it is preferable to substitute $H_2 = 0$, i.e., the second combustion stage is dispensed with altogether. A solution between these extremes never brings any advantage as far as efficiency is concerned. Nevertheless, it is sometimes selected when the relationship of the gas-turbine output to that of the steam turbine has to be shifted, either for economic reasons or to obtain full benefit from an existing gas or steam turbine.

The results of investigations which have been carried out may be summarized as follows:—

(a) The superiority of a combined installation over a plain steam plant is given by eqs. (5) and (6). If, now, the ideal gas-turbine efficiency

$$\eta_{GT}^{*} = \frac{\eta_{el}\,(E - C) + \eta_R R}{E} \qquad .. \qquad (18)$$

is introduced, the numerator contains the output of a gas turbine with heat recovery and the denominator represents the work of expansion which would be equal to the heat input to a gas turbine with a perfect heat exchanger and without any losses in the combustion chamber. If this ideal gas-turbine efficiency were substituted in eq. (5), the gain in efficiency could be expressed in the simple form

$$\eta - \eta_0 = (\eta_{GT}^{*} - \eta_{th})\,\frac{E}{H} \qquad .. \qquad .. \qquad (19)$$

(b) The superiority of a combined plant over a plain gas turbine with heat recovery may be expressed equally simply if a further "ideal" gas-turbine efficiency is introduced, defined by $\eta_{GT}^{**} = \eta_{GT}/\eta_H$.

This corresponds to the efficiency of the gas turbine with heat recovery, referred to the actual heat input to the gas, i.e., without combustion-chamber losses, so that

$$\eta - \eta_{GT} = (\eta_{th} - \eta_{GT}^{**})\,\frac{\eta_H\, H_2}{H} \qquad .. \quad (20)$$

(c) From the last two equations it is possible to derive the following criteria for the installation with the best efficiency :—

$\eta_{th} > \eta_{GT}^{*}$ plain steam plant,
$\eta_{GT}^{*} > \eta_{th} > \eta_{GT}^{**}$ combined plant with additional combustion,
$\eta_{GT}^{**} > \eta_{th}$ gas turbine with heat recovery, but no additional combustion.

The combined installation with additional heating is thus advantageous only when the thermal efficiency of

the steam cycle η_{tth} is between the limits η_{GT}* and η_{GT}**.

Fig. 7 shows the efficiency of a straightforward steam installation η_0 and that of a combined steam and gas plant η_l for a temperature t_3 of 600°C and 750°C before the gas turbine, in terms of thermal efficiency η_{tth} of the steam turbine. From this illustration it can be seen that an improvement of $\Delta\eta_l = \eta_l - \eta_0$ can always be achieved with the combined installation. The improvement $\Delta\eta_l/\eta_0$ decreases with increasing η_{tth}, as may be seen in Fig. 8. With higher temperatures at the inlet to the gas turbine the improvement is correspondingly greater.

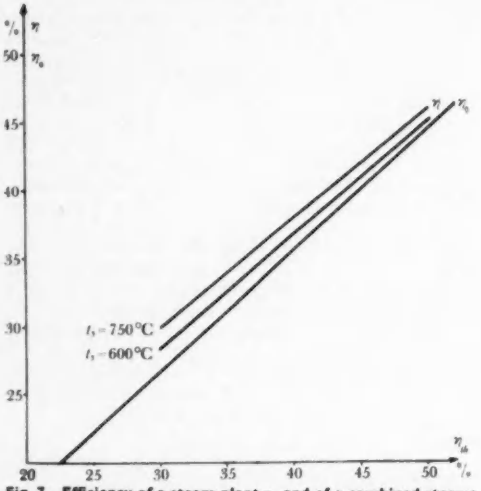

Fig. 7. Efficiency of a steam plant η_0 and of a combined steam-gas turbine installation according to system D, in terms of the thermal efficiency η_{tth} of the steam turbine at a gas-turbine inlet temperature of 600 and 750°C.

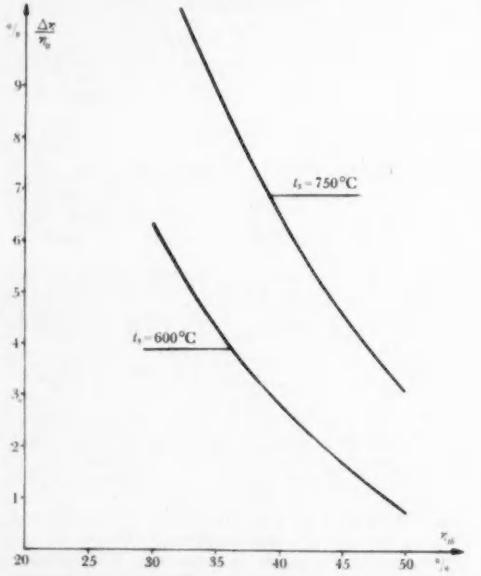

Fig. 8. Improvement in efficiency $\Delta\eta_l/\eta_0$ as a function of the thermal efficiency η_{tth} of the steam turbine for installations according to system D, at a gas-turbine inlet temperature of 600 and 750°C.

If, in a gas-turbine set, the air is compressed in n stages with intercooling, and expansion takes place in m stages with reheating, it is no longer permissible to use the equations (15) and (15a) for π. For such cases, however, it is possible to derive appropriate equations.

Since numerical investigations of systems including intercooling, even with recovery of the dissipated heat in a partial feedwater current, so far have resulted in deterioration of the efficiency and since, on the other hand, the gain with reheating has been very modest and obtainable only under definite conditions, it is believed that such combinations are not interesting for conventional gas-turbine inlet temperatures.

If any importance is attached to the economics of a particular set under partial load, exhaustive investigations are necessary, and alternatives such as, for instance, the provision of a by-pass combustion chamber, a split-shaft gas turbine, or a gas-turbine set designed for the principal load and overload output from supplementary boiler fans, should be considered.

Economic Comparison

Primarily it is of interest to know which of the systems A to G is the most economical. One variant, i.e., scheme B, can be eliminated straight away, since it was merely introduced for fundamental reasons and is obviously a good deal more expensive than C, besides having a poorer efficiency.

System F can only be recommended in preference to E in special cases. Admittedly, it offers a proved thermodynamic advantage, but this is quite insignificant. If a plant is only intended to supply heat and no electricity, or if, for any reasons, as much as possible of the power gain is to be obtained from the steam turbine and as little as possible from the gas turbine, system F will be adopted.

Compared with system C (without air heater), system G is rather at a disadvantage from the efficiency aspect, but is nevertheless very interesting in situations where, for other reasons, a gas turbine is employed as the main machine.

In the following remarks, only the systems A, C, D, and system E without air heater will be compared with one another. The installations were first calculated thermodynamically with oil as the fuel and the prices estimated as accurately as possible in the limited amount of time available for this investigation.

As a result of these investigations it can be stated that system E without air heater is by far the most favourable variant. Not only is the improvement in efficiency of this installation greatest, but the installation cost per kW is also lowest. This low cost is mainly due to the boiler being pressure-charged, implying, according to latest investigations, that appreciable savings in weight and price can be anticipated.

Comparison of the four systems also works out in favour of system E for other fuels, such as natural gas or blast-furnace gas. This conclusion ought also to apply for coke-oven gas, although this has not been investigated in detail. For coal-burning systems, it is only feasible to employ system A or D, the former being obviously preferable from the cost aspect. If several fuels have to be used, the installations naturally become more complicated, although liquid and gaseous fuels can both be burned in plants of system E. If coal is added to these, it will be better to adopt system A and connect it in parallel with E on the steam side.

Stratified-Charge Systems for Spark-Ignition Engines

By J. BEAUDRY, L. D. CONTA, J. L. BASCUNANA, and P. DURBETAKI

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pp. 57-59, 3 illustrations.

STRATIFIED-CHARGE operation is an attempt to confer on spark-ignition engines the advantages of the variable mixture ratio enjoyed by diesel engines. Also, because a stratified-charge engine operates with a large amount of excess air under normal conditions, cleaner and more complete combustion can be obtained.

In normal spark-ignition engines, a nearly homogeneous fuel-air mixture is supplied by a carburettor, ignited at one place by a sparking plug, and consumed by an advancing flame front which traverses the combustion chamber. The fuel/air ratio is held approximately stoichiometric, since only such mixture ratios can reliably support flame propagation. Power is controlled by a simple throttle valve.

The stratified-charge engine uses a non-homogeneous fuel-air mixture, which is stoichiometric near the sparking plug at all loads and which varies from stoichiometric at full load to air alone at light load in regions remote from the sparking plug. The heterogeneous mixture serves to increase the ignition energy, so that a rapid rate of combustion is maintained and the mixture kept ignitable.

Various techniques have been developed for producing the required mixture distribution, two of the most important of these being the system devised in the U.S.A. by Broderson, and the system devised in France by the Institut Français du Pétrole.

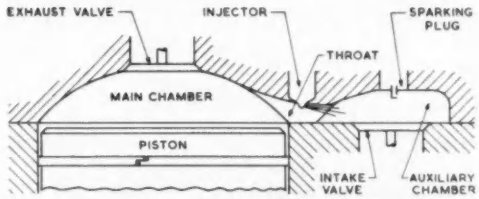

Fig. 1. Design of combustion chamber used in the Broderson system for producing charge stratification.

In the Broderson system, use is made, as shown in Fig. 1, of an auxiliary chamber containing the intake valve, the sparking plug, and a fuel injector. Operation of the engine is based on the reversal of air-flow direction when the piston passes its bottom-dead-centre position. Fuel injected into the auxiliary chamber during the suction stroke is carried into the main chamber by the incoming air. Fuel injected during the compression stroke is held in the auxiliary chamber by the back flow of air and mixes only with the air in this chamber. Under light loads, injection takes place only during the early part of the compression stroke. Since no fuel is carried into the main chamber during compression, only air is present in this chamber. Under higher loads, the injection period straddles the bottom-dead-centre position, so that more fuel enters the main chamber. Consequently, a near-stoichiometric mixture surrounds the sparking plug at all loads, while the fuel/air ratio in the main chamber varies from near-stoichiometric at full load to very lean or only air at light load. Under heavy loads, the main chamber contains an inflammable mixture, and combustion occurs in the normal way. Under light loads, however, the mixture in the main chamber is too lean to support flame propagation. Combustion of this lean mixture results from the rise in pressure and temperature caused by the burning mixture in the auxiliary chamber and by the blast of the hot reacting gases being injected into the lean mixture from the auxiliary chamber.

Work on the Broderson system is continuing, and four different engines have so far been converted, each with a radically different combustion-chamber arrangement. All these engines have operated satisfactorily and show that this method of stratification is not critical with respect to design characteristics. They have, however, behaved differently with regard to the degree of roughness and noise produced, and also in the spark advance required by each, indicating that variations in combustion-chamber design can control the gas-combustion process by changing the mixing and turbulence patterns. All four engines have shown themselves to be relatively insensitive to deviations from the optimum values of such operating parameters as spark advance and injection timing. At present, only gaseous fuels have been used with these engines, but reconversion to liquid injection is planned.

With the Broderson system, very good fuel economy has been obtained over almost all the load range of the engine. The only exception is a fuel-consumption peak in the middle of the load range, where a sharp rise is encountered, apparently at a point where the mixture in the auxiliary chamber becomes over-rich and some fuel must be carried into the main chamber. It is suspected that the reason for this rise in consumption is insufficient turbulence and mixing of the burning products from the auxiliary chamber with the lean mixture in the main chamber, resulting in slow or incomplete combustion of the main charge. Good fuel economy is again obtained as the load is increased beyond the middle range. It is believed that the use of a higher compression ratio may cure these mid-range troubles, and that changes in combustion-chamber configuration to improve fuel distribution and promote turbulence and mixing of the burning gases ejected from the auxiliary chamber with the lean main-chamber mixture may also help in this respect.

The system developed by the Institut Français du Pétrole (IFP) is different from the Broderson system, and uses carburation to form the heterogeneous mixture, the mixture being produced in the combustion chamber merely by dividing the carburetted mixture into two separate streams with completely different fuel/air ratios. Fig. 2 shows an IFP-Renault-CNRS engine modified for heterogeneous carburetion, the only alteration to the engine being the addition of a small-diameter tube in the intake port for discharging the rich mixture as close as possible to the intake valve. The encircled numbers in Fig. 2 show alternative sparking-plug positions, position No. 1 proving to be the most satisfactory.

Tests with the IFP engine have shown that the localized increase in the fuel/air ratio in the vicinity of the sparking plug is sufficient to provide satisfactory combustion of a mixture with a low overall fuel/air ratio. Satisfactory operation has been obtained with this engine for a

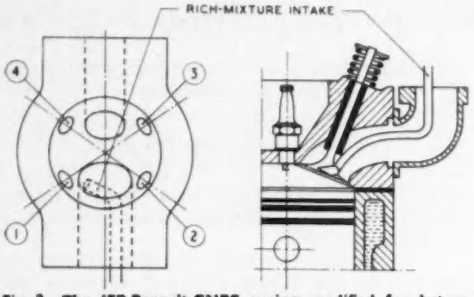

Fig. 2. The IFP-Renault-CNRS engine modified for heterogeneous carburetion.

relative mixture-strength ratio (i.e., that of the prevailing fuel/air ratio to the stoichiometric fuel/air ratio) down to 0·55 and up to a value in excess of unity. By comparison, the minimum value for normal carburation is 0·85. To change the fuel/air ratio, fuel is added to the intake air to obtain the desired output. In this way, the heterogeneity of the mixture is lowered as the overall value of the relative mixture-strength ratio increases.

Specific fuel consumptions equal to or better than the minimum values obtainable with normal carburation are achieved with the IFP system. Because the engine can be operated at full load, as though it had standard carburetion, no decrease in the maximum output occurs, other than that due to decreased volumetric efficiency caused by the presence of the rich-mixture tube. Under 50% and 100% load conditions, regulation is obtained by varying the fuel only, as in diesel engines. Under loads below 50%, output is controlled by throttling, as with conventional carburetion. The minimum values of relative mixture-strength ratio lie between 0·55 at full throttle and 0·65 for idling, but deviations from these values are tolerable—more so than for normal carburetion, where deviations in relative mixture-strength ratio cause larger increases in specific fuel consumption.

In these tests on the IFP engine, two carburettors were used, one for the rich-mixture tube, and the other for the standard intake pipe, changes in overall fuel/air ratio and heterogeneity of the mixture being effected by manual adjustment. In practical applications, these adjustments must be made automatically, and only one carburettor should be used. In this connection, a single-carburettor induction system has been proposed, in which use is made of two interconnected butterfly valves to keep the fuel/air ratio constant in the throttling range, a third butterfly valve being used in the unthrottled range to direct a portion of the rich mixture into the main induction pipe.

Because of the rich environment, it was originally believed that trouble would be experienced in the form of sparking-plug fouling and deposits in the rich-mixture tube but, in fact, none of these troubles developed. The lean mixture might ordinarily cause early deterioration of the exhaust valves with normal carburetion, owing to slow combustion. In the IFP system, however, as in diesel engines, the problem does not arise, because an adequate rate of combustion lowers the exhaust-gas temperature in proportion to the decrease in the fuel/air ratio.

With unthrottled operation at fuel consumptions lower than the minima obtained with normal carburetion no measurable quantity of carbon monoxide could be found. It should be noted that, with normal carburetion, the carbon monoxide content of automobile exhaust gases varies greatly with carburettor adjustment and operating conditions and is negligible only when the relative mixture-strength ratio is below 0·95. When this ratio is 1·05 (a more likely value), the carbon monoxide content is 2% and, under idling conditions, varies from 2 to 6%. By comparison, the IFP engine was found to have a carbon monoxide content in the exhaust of 0·008% when idling with a partially closed throttle and with an overall relative mixture-strength ratio of 0·65. As full load is approached, the IFP system approximates the conditions found with normal carburetion, and the carbon monoxide content is the same in both cases. However, if the output were reduced by 5%, the carbon monoxide problem would be eliminated.

Electrical and Metallurgical Factors Affecting Welding-Arc Stability

(*Concluded from page 82*)

the rear. Closure of the plate gap will eliminate the field distortion in the centre of the weld. End symmetry is achieved, often unwittingly, by the use of run-out tabs.

Fig. 2 shows field dislocation caused by asymmetrical metal distribution. Reluctance is increased in the region of the circular opening, from which the arc deflects. This problem can be alleviated by temporarily filling the opening with a close-fitting plug of conductive material. The most suitable filling material can be determined by experimentation.

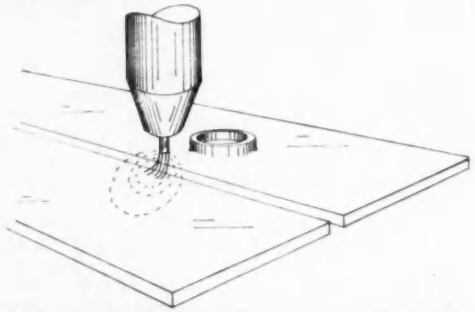

Fig. 2. Arc instability caused by an asymmetrical welding assembly.

Magnetic manipulation of the arc has been explored for improving arc stability in welding 4330 steel and for achieving improved welded properties in aluminium. By clamping a transducer on an electrode holder, it is possible to oscillate the arc in a frequency range between 3 and 10 cps. As expected, the arc deflection is normal to the field of the laminated electromagnet. Polarity reversal permits considerable deflection of the arc to either side of the electrode, the range of deflection being limited by automatic voltage control. Deliberate deflection of the arc causes the apparent arc voltage to vary, and the voltage control picks up this variation. A sensitivity control allows a variation of 0·2 V. With greater signals, voltage-control hunting becomes a problem. Slight oscillation improves both the top and the bottom bead configuration on 4330 steel. Magnetic manipulation produces welded properties in aluminium comparable with those obtained under normal conditions. It must, however, be appreciated that, as this procedure is so complex, it has little more than a novelty value.

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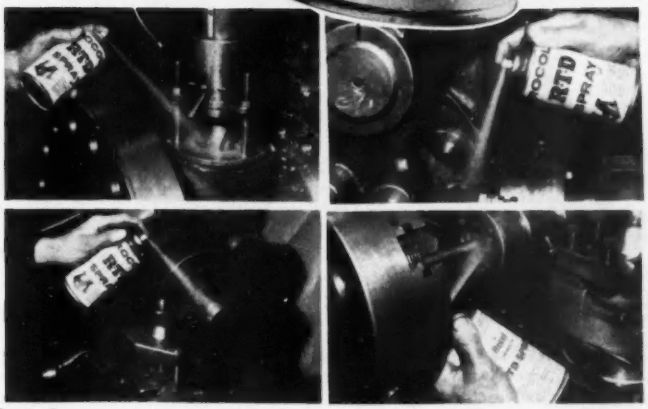

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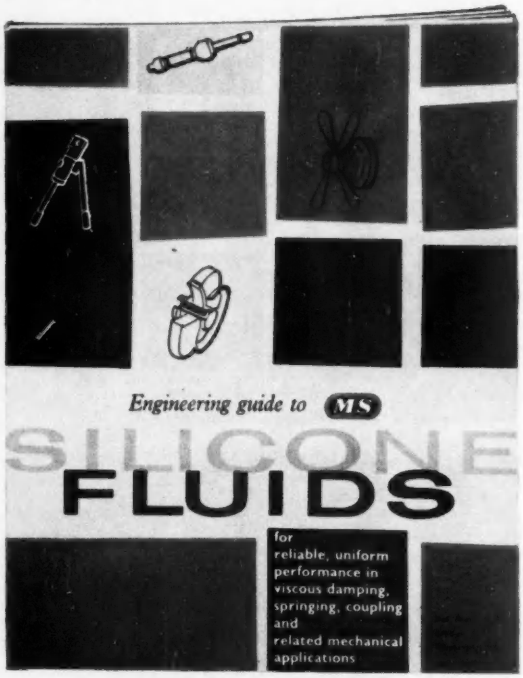
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The Machining of Difficult-to-Deform Metals

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As the speed of airborne vehicles advances beyond Mach 2·2, the use of conventional light alloys as structural metals is no longer possible. The criteria for selection of the alternative metals are high strength, a high modulus/weight ratio, and good strength/temperature characteristics. It follows that those metals with relatively high density require to be very strong to become competitive in the extent of their use and, since hardness is a function of strength, they will be difficult to machine. Most refractory metals have a low conductivity and specific heat. The crystal structures and slip mechanisms of other preferred materials are resistant to deformation. Collectively, the machining of those metals which are attractive as constructional materials for higher supersonic speeds produces problems which have demanded many changes in the established methods of metal cutting.

Basically, there exists only a small margin between the strength of hardened ultra-high-tensile steels and that of the available high-speed tool materials. As much rough-machining as is practicable is consequently carried out in the annealed condition. Finish-machining to close-tolerance dimensions must, however, be effected in the hardened state to permit correction of distortions arising from heat treatment, so that, whilst the extent of the task can be curtailed, it cannot be avoided altogether.

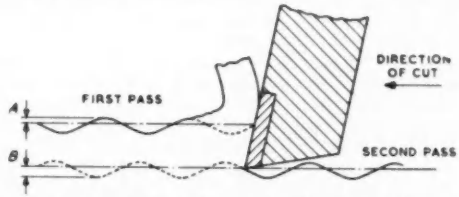

Fig. 1. Variation in depth of cut produced by consecutive passes whose paths are modulated by an impressed vibration upon the steady feed condition.

Engineers have hitherto shown a reluctance to use cemented carbides on account of their well-known fracture characteristics under impact loading. Although entry and exit conditions produce the widest stress fluctuations at the tool cutting surfaces, machine-tool vibration also contributes significantly. Vibration arises from non-linear transmissions resulting from drive errors, slide and bearing imperfections, eccentrically mounted or ground cutters, and insufficient stiffness or damping in the structure, tool-support, or work-holding fixtures. Collectively, these results produce instability modes, during which the depth of cut and value of the applied cutting forces fluctuate widely and lead to rapid tool wear. Fig. 1 illustrates the variation on depth of cut produced by consecutive passes, the paths of which have been modulated by an impressed vibration upon the steady feed condition.* Consecutive passes of the tool produce on the cut surface a regeneration of the undulations existing at the previous pass, the amplitude and phase being modulated in accordance with the cutting conditions. If the amplitude of *B* in Fig. 1 is smaller than that of *A*, stable machining conditions are approached. If the amplitude of *B* exceeds that of *A*, the instability persists.

The amplitude of the variation about the steady-state cutting force is obviously dependent on the material being cut, and the effect is more serious with harder materials. From this aspect, arbor-mounted cutters should be avoided or should be selected with the largest possible diameter and adequately supported at each end to effect maximum stiffness in the cutting system. Shank-mounted cutters, preferably supported at the spindle nose, offer improved stiffness and produce the best cutting conditions. Essentially, heavy-duty cutters require an adequate body and tooth section. With carbide inserted-tooth or brazed-tip cutters, the supporting section and insert or tip require generous dimensions. Brazing must not be suspect and must be carried out in a controlled furnace. Cleaning by vapour-blasting and copper deposition prior to brazing should ensure uniformity and consequent freedom from catastrophic breakdown.

Speeds, Feeds, and Depth of Cut

Provided that the machine tool and spindle drive system are sufficiently rigid and adequately powered, depth of cut does not exert a significant influence on steady-state cutting conditions, any adjustment bringing into engagement a wider band of the cutting edge. An increase in cutting speed, however, increases the shear and rake-face velocities and increases the shear-plane angle. Similarly, a reduction in feed decreases the width of the shear-plane spacing and inversely must increase its frequency. Thus, an increase in speed and the selection of finer feeds are beneficial, since together they increase the friction and shear velocities, bringing about a reduction in the shear strength of the metal as a result of the increase in temperature at the site of the deformation. Provided that cooling is applied in a discriminating manner, so as to reduce the temperature of the tip and not that of the chip, the practical advantages of this method in cutting fully hardened high-strength steel can be pressed extensively. The method succeeds best where the conductivity and specific heat of the metal are good; refractory metals, however, do not permit such a significant advantage, although diffusion and fracture wear are vastly improved and crater formation is avoided. Figs. 2 and 3 show respectively depth of cut and feed as functions of average chip/tool interface temperature, and it will be seen that, for the two metals concerned, interface temperature assumes a constant value for a selected cutting speed at depths of cut greater than the tool-nose radius, while the temperature increase with an increase in feed is linear. Practical applications of this process have been reported in connection with milling and turning operations.

On account of the diminution in strength with an increase in temperature, high-speed tool steels can obviously be employed only at the lower ranges of machining speeds. Asperity encounter, fusion, and

* S. A. Tobias: *Int. Jour. Mach. Tool Des. Res.*, No. 1, 1961, p. 2, Pergamon Press.

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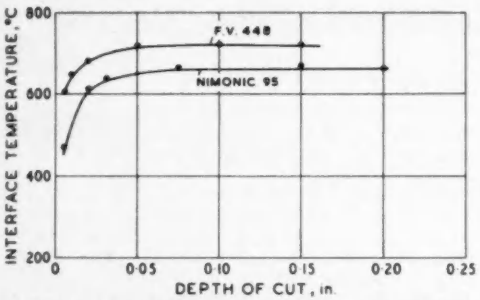

Fig. 2. Tool/chip interface temperature as a function of depth of cut for F.V. 448 steel and for Nimonic 95, using dry carbide tools with a nose radius of 0·05 in. and under conditions of constant cutting speed and feed.

	F.V. 448	Nimonic 95
Cutting speed [fpm]	418	103
Feed [in./rev.]	0·01	0·01
Carbide grade	Teco EEV	Teco CL

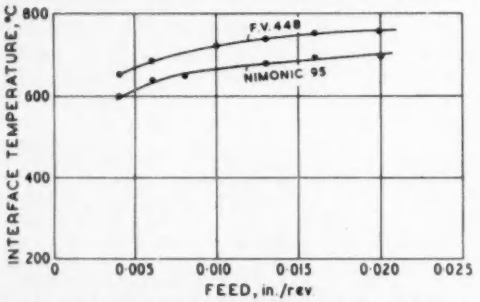

Fig. 3. Tool/chip interface temperature as a function of feed for F.V. 448 steel and for Nimonic 95, using dry carbide tools and under conditions of constant cutting speed and depth of cut.

	F.V. 448	Nimonic 95
Cutting speed [fpm]	410	103
Depth of cut [in.]	0·10	0·10
Carbide grade	Teco EEV	Teco CL

plucking wear account for tool breakdown, the latter becoming significant at the maximum permissible speeds for the tool/metal combination.

The Selection of Tool Materials

The selection of a suitable material for cutting high-strength steels and other materials generally involves the use of high-speed tools, cemented-carbide-tipped tools, or ceramic-tipped tools. Details of these tools are discussed separately in the following.

High-Speed Tools

High-speed tool steels suitable for cutting high-strength steels contain varying amounts of tungsten, with cobalt, chromium, and vanadium additions, or are alloyed with molybdenum and similar additions. Tungsten steels possess an advantage at higher cutting speeds, since the range exhibits hot hardness as a result of the slow precipitation of tungsten carbide from the tempered martensite. Molybdenum high-speed steels therefore usually contain a percentage of tungsten. As tungsten is somewhat susceptible to thermal and

TABLE I: COMPOSITION [%] OF TYPICAL HIGH-SPEED TUNGSTEN AND MOLYBDENUM TOOL STEELS

W	Cr	V	Co	Mo
18	4	1 to 5	0 to 12	0·5
2 to 6	4 to 5	2	1 to 5	5 to 8
5 to 6	4 to 5	2 to 4	—	4 to 6
6	4 to 5	2 to 4	8 to 12	5 to 9

mechanical shock, cobalt is added to tungsten and molybdenum steels to improve impact properties and temperature characteristics. Typical compositions of high-speed tungsten and molybdenum tool steels are given in Table I.

In recent years, interest has been aroused in the development of cast high-speed milling cutters, particularly with regard to the facilities offered by investment casting. In these cutters, alloys of tungsten, chromium, and cobalt, tempered to a DPN hardness of 700 to 850, are employed, typical compositions being 10 to 15% tungsten, 30 to 32% chromium, 30 to 50% cobalt, 3% iron, and 3% nickel.

When cutting steels with an ultimate tensile strength in the range of 100 tsi, the use of high-speed tool steels will be restricted in their upper range of machining speeds. These tools should be wet-ground, employing soft wheels which break down with relative freedom; in this way, fresh facets are presented which cut without burning the surface of the tool.

Cemented Carbides

Complex cemented-carbide mixes containing titanium, molybdenum, tantalum, and niobium have been developed to control grain size, to improve the strength of the matrix bond, and to reduce stress-cracking and diffusion wear. These materials are of considerable value when cutting the ultra-high-tensile steels. When machining titanium alloys, however, it has been observed that diffusion, plucking, and abrasive wear become most marked at the higher permissible cutting speeds. Tests show that straight tungsten carbide tips best withstand diffusion wear, particularly at high cutting speeds. The presence of carbide and oxide formations on the machining stock produces abrasion wear, so that selection should be made among the harder grades of tungsten carbide. Those carbide grades possessing a finer particle size perform better than those selected from more coarsely balled carbide.

The knowledge gained in machining titanium has been applied to cutting metals possessing similar refractory characteristics and crystal structures. Beryllium, which has a hexagonal close-packed structure, machines with a discontinuous chip form in the manner of cast iron and has a generally abrasive characteristic. The selection of cemented carbide tips for titanium and beryllium is found to correspond. The particle size in the cemented mix has a considerable bearing on the ability of the tip to withstand wear, irrespective of the metal being cut. Tests indicate a significant improvement below a size of 5 microns, when lattice imperfections are few and materials exhibit much greater strength. Table II lists a selection of carbide grades and their manufacturers, as recommended for machining high-strength steels with a DPN hardness of 560 to 650, ferritic heat-resistant stainless steels (DPN = 320), titanium alloys (DPN = 320 to 340), Nimonic 90 to 100 alloys (DPN = 320 to 420), and beryllium alloys.

The impact encountered by the tool on entry and exit from the work material produces wide variations in

TABLE II: SELECTION OF CARBIDE GRADES FOR VARIOUS MATERIALS

Manufacturer	Material				
	High-Strength Steel	Stainless Steel	Titanium Alloys	Nimonic Alloys	Beryllium Alloys
Firth, Brown	—	—	PX. 248	—	PX. 248
Wickman	XL1	XL1	NS	—	NS
Teco	—	EEV	—	CL	—
Kennametal	K2S	—	—	—	—
B.S.A.	R.T.	I	—	—	—
Sandvik	S.2	—	—	—	—

compressive and tensile stress at the cutting edges, leading to fracture wear. The first development in the cutting of hard metals concerned the introduction of the helical carbide tooth, which was brazed to the cutter body of cylindrical and taper mills. Originally produced by hot-forming methods, the present green-moulded and compacted product is made up in short sections to reduce the stresses in the braze during cooling. This method incidentally avoids excessive grinding, and cheapens and facilitates replacement when fractures occur. The first specimens were made by Production Tool Alloys Ltd. and tested on S.120 (100-tsi) steel. Surface finish showed an improvement, and the cutting forces were considerably reduced. Fracture wear was offset, and the tool lasted considerably longer between regrinds.

Face-milling presented a somewhat different problem to cylindrical milling. Invariably, conditions approximating climb-milling must be faced where entry to the stock produces the maximum impact stress. The contact made by the cutter tooth on entering the stock is rectangular, compatible with full depth of cut and feed. In experimenting with the chip form and entry conditions, it was observed that, since the intersection of a line with a circle occurs at a point, the cutter teeth could be given an arcuate form and, by making the radial approach angle significantly negative, similar conditions of point contact could be achieved on entry and exit.

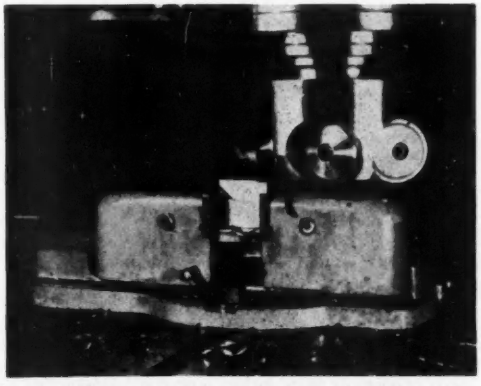

Fig. 4. Milling cutter with circular inserted carbide teeth, having a 45-deg. negative radial rake.
(Courtesy of The College of Aeronautics, Cranfield)

A 45-deg. negative radial rake ensures the outward flow of the chip stream, widens and thins the chip, reduces the applied compressive stress, and avoids impact by varying the section progressively at entry and exit, extending this phase. A view of the cutter body is shown in Fig. 4. The resulting chip, which has a crescent-shaped cross-section, possesses thinned edges and has a pronounced and distinctive quill-like geometry at its extremities, as shown in Fig. 5. The achievement of point entry to the work is evidenced by the facility with which the chips cut into the fingers. The derivation of the chip form has enabled carbide inserts to be employed without fracture in cutting 120- to 140-tsi steels with a hardness of DPN 700.

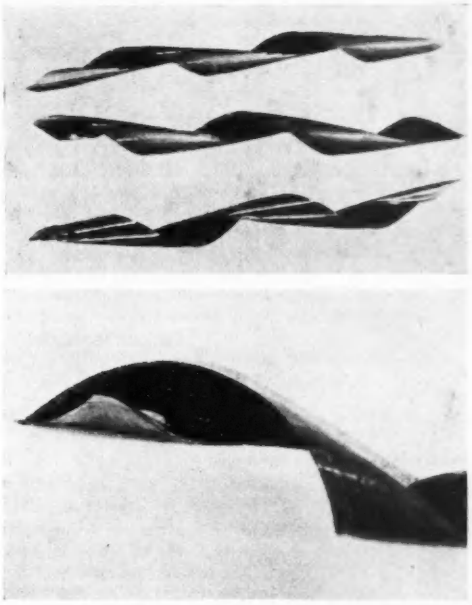

Fig. 5 Chips produced from a 120-ton alloy steel, using the milling cutter shown in Fig. 4 at a cutting speed of 80 fpm and a depth of cut of 0·025 in. The illustration shows (above) a selection of typical chips (x2), and (below) a close-up (x7) of part of a chip.
(Courtesy of The College of Aeronautics, Cranfield).

Ceramic Tips

The bulk of investigations into machining with ceramics has been concerned with alumina-based materials. The cheaper grades are satisfactory for cutting low-carbon steels, but harder materials can be cut only by attention to particle size, alloying, and pressing. Considerable research has yet to be done before product uniformity can ensure freedom from chipping, compressive and thermal stress cracking, and pronounced diffusion wear.

Comparative tests on the performance of ceramic tools and cemented carbides in connection with machining S.99 (a 100-ton 2½% Ni-Cr-Mo steel) showed that the best grade of ceramic tool gave the highest rate of stock removal and tool life, excelling at feed rates of 0·005 and 0·010 in./rev. The performance of the carbides was reasonably consistent, yielding optimum results at cutting speeds of from 100 to 200 fpm. On the other hand, the best grade of ceramic tool, while offering higher machining speeds (600 fpm) with a fine feed rate of 0·005 in./rev., lost its advantage with heavier feed rates. On scale-removal tests, carbides were superior to ceramics. Fig. 6 shows the results of these tests on S.99 steel, in terms of tool life as a function of cutting speed,

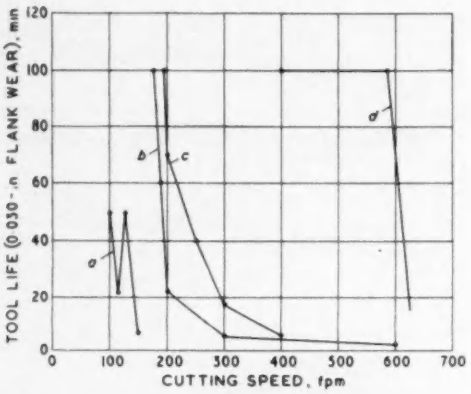

Fig. 6. Tool life as a function of cutting speed when machining S.99 steel with carbide and ceramic tools at a feed rate of 0·005 in./rev.
(a) Wrongly selected carbide grade.
(b) Good carbide grade.
(c) Average of good-quality ceramics.
(d) Exceptionally good ceramic.

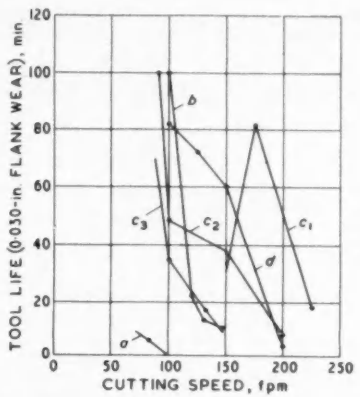

Fig. 7. Tool life as a function of cutting speed when machining S.99 steel with carbide and ceramic tools at a feed rate of 0·020 in./rev.
(a) Wrongly selected carbide grade.
(b) Good carbide grade.
(c_1), (c_2), (c_3) Good-quality ceramics.
(d) Exceptionally good ceramic.

using a feed rate of 0·005 in./rev., while Fig. 7 shows the results corresponding to a feed rate of 0·020 in./rev., from which it will be seen that, for a comparable tool life, cutting speeds at this heavier feed rate have dropped considerably.

With ferritic stainless steel, a considerably different picture is presented. In this case, the best tool life achieved with any of the ceramic tools tested, irrespective of speed and feed, was 15 min, corresponding to a cutting speed of 400 fpm, a feed rate of 0·005 in./rev., and a depth of cut of 0·05 in. By comparison, the carbides performed excellently, giving a life of 45 min at a cutting speed of 600 fpm and with twice the feed rate and depth of cut. At a cutting speed of 500 fpm, the ceramic tools had a life of only 1 min.

TABLE III: RESULTS OF MACHINING TESTS ON NIMONIC 90

Cutting Speed [fpm]	Feed Rate [in./rev.]	Depth of Cut [in.]	Tool Life [min]	Tool Tip
100–200	0·015	0·050	<1¼	Ceramic
80	0·015	0·050	<3	Ceramic
80	0·015	0·050	>70	Carbide
20	0·005	0·100	<7	Ceramic

TABLE IV: RESULTS OF MACHINING TESTS ON F.V. 448 STEEL

Cutting Speed [fpm]	Feed Rate [in./rev.]	Depth of Cut [in.]	Tool Life [min.]	Tool Tip
600	0·005	0·050	<8	Ceramic
600	0·015	0·100	<8	Ceramic
600	0·010	0·100	45	Carbide
50–400	0·005	0·050	<15	Ceramic
50–400	0·015	0·100	<7	Ceramic

The Nimonic alloys provided a somewhat similar comparison, correctly selected tungsten carbide tools performing satisfactorily at a cutting speed of 80 fpm, with a tool life exceeding 70 min, as shown in Table III. On the other hand, this table shows that the best performance obtained with ceramic tools resulted in a life of about 7 min at a cutting speed of 20 fpm, as compared with the life of 100 min at 600 fpm obtained when machining S.99 steel, as shown in Fig. 6. Since Nimonic 90 and F.V. 448 steel both possess a high chromium content and a low carbon content, it is suspected that the pronounced diffusion and plucking wear noticed when machining these materials with ceramic tools is due to migration of chromium to the alumina tip. The results of tests on the creep-resistant F.V. 448 steel are given in Table IV, from which it is concluded that alumina-based ceramic tips are not nearly so suitable for machining high-chromium alloys of this type, whereas they are quite satisfactory for machining the S.99 steel previously mentioned.

The Machining of High-Strength and Heat-Resistant Stainless Steels

Aircraft constructional steels, which may require machining in the fully heat-treated condition, belong to the heat-treatable martensitic low-alloy group and the high-chromium ferritic-martensitic creep-resistant varieties. Certain hot-strength die steels may be included, but machining for their original purpose as dies would almost invariably be carried out with solid tungsten carbide burrs, using spindle speeds of 80,000 rpm and upwards. It is customary to encounter in the aircraft industry these units employed as copying accessories on the finest die-sinking machines, and their utilization represents a considerable advance from the calamitous use of solid tungsten carbide on copy profilers having spindle speeds of 6000 to 8000 rpm. The successful use of solid tungsten carbide is compatible with the recommended selection of high cutting speeds and light cuts in order to produce low resulting impact forces.

A wide range of high-strength steels is encountered in the aircraft industry, those typical of the range being listed in Table V. Of these high-strength steels, S.120 and SAE 4340 are heat-treatable low-alloy steels, Vascojet 1000 and Jessop H.50 are hot-strength steels, and F.V. 448 is a creep-resistant steel.

If the general recommendations concerning feeds are adhered to, these steels can be machined up to 60 fpm with high-speed tools having cobalt additions. The hardness of steels to be machined with tools among the high-speed range should not greatly exceed 380 DPN but limited tool life can be achieved at cutting speeds of 8 to 10 fpm with materials of 640 DPN. Higher hardness

TABLE V: COMPOSITION [%] OF HIGH-STRENGTH STEELS

	C	Si	Mn	Ni	Cr	Mo	V
S. 120	0·35	0·10–0·35	0·5–0·6	2·5	0·5–0·8	0·4–0·7	—
SAE 4340	0·30–0·40	0·20	0·6–0·8	1·6–2·0	0·7–0·9	0·2–0·3	—
Vascojet 1000	0·40	0·90	0·3	—	5·0	1·3	0·45
Jessop H.50	0·37	1·10	—	—	5·0	1·3	1·10
F.V. 448	0·12	—	—	0·45	10·5	0·75	0·15

values render machining virtually impossible. At 640 DPN, cemented carbide of the correct grade will cut from 90 to 150 fpm, and its use has obvious advantages. In face-milling, an axial rake of 5 deg. and a radial rake of 20 deg. negative are desirable. The adoption of negative radial rake and generous nose radii has been shown elsewhere to improve entry and exit conditions and governs the radial outward flow of the chip stream. Whatever the type of tool, obtuse-angled geometry, which produces chip-compacting tendencies, should be avoided. A pronounced negative face rake applied to single-point tools and negative helix angles selected for end-mills will effect an increase in the deforming forces, thereby adding to the already arduous conditions of cutting; the incipient built-up edge conditions will also add to friction. Chip-breakers are discouraged for the same reasons.

Coolants should be selected for their inhibiting qualities and ability to provide low shear-strength lamellae by active combination with the deformed surface in sliding contact with the tool. Overcooling sustains the strength of the chip at the shear plane. At high machining speeds, overcooling can produce a hard martensitic skin on the machined surface of these high-strength steels, which harden by a precipitation process, and the effect should be avoided during finish-cutting. An example of this effect on the surface of machined stock is shown in Fig. 8.

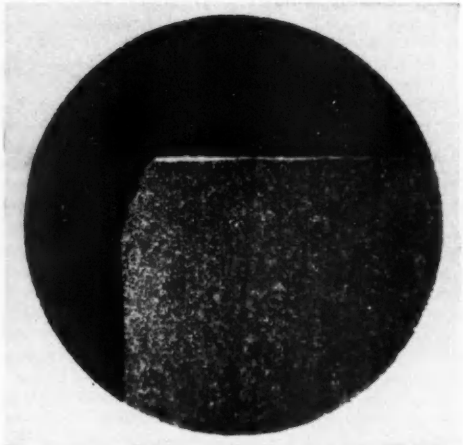

Fig. 8. Martensitic formation on the surface of machined stock, produced by overcooling at high cutting speeds.

With fully hardened ultra-high tensile steels, drilling and tapping are virtually impracticable, and much of the work is carried out at lower hardness values. Drills require a thick web section, a high helix angle, and a spiral point to deal with entry and break-through conditions. Carlstedt boring heads and gun reamers are sometimes employed on holes requiring a good surface finish. The Strasmann reamer has proved in tests to have considerably longer life than straight- or spiral-flute reamers. Final sizing of the holes invariably appears to demand reaming and grinding. Taps require full form-relieving, and the number of teeth engaged in cutting must be restricted by omission of teeth—the "skip-tooth" tap; alternatively, interstage taps must be selected according to the capability of the shank to transmit the required torque. Torque-limiting devices should be employed. Torque-meter readings show sharp increments as each tap tooth enters progressively into engagement, and entry should be effected slowly to prevent chipping or fracture.

The Machining of Beryllium

In addition to high temperature strength and good corrosion resistance, beryllium has a low specific gravity (1·85), a remarkably high Young's modulus (44×10^6 psi), and a high thermal conductivity (0·385 cal/cm²/cm/sec/°C) and specific heat (0·475 to 0·516 cal/gm/°C at 30 to 100°C). Its modulus/density values recommend it as an airborne constructional material. Although its low density seems to be disadvantageous from the point of view of metal-cutting, the remaining constants in the interface-temperature equation indicate that a large amount of shearing and friction energy produced in the cutting process can be carried away in the chip, i.e., without undue heating of the tool tip.

The metal is particularly difficult to deform at room temperature. It is reported that the slip system of the single crystal restricts the major elongation to the $\{10\bar{1}0\}$ planes and $<1120>$ direction. Predominant twinning occurs on the $\{10\bar{1}2\}$ planes and in the $<10\bar{1}1>$ direction under compression and tension conditions. Basal slip (0001) occurs more markedly in compression, only small amounts being observed in tension. Essentially a brittle material, beryllium has sufficient isotropic ductility above 485°C to commence plastic deformation. Twinning is considered to be the main mode of deformation during hot working.

The hardness of beryllium is dependent on its purity, particle size, and treatment. Thus, rod extruded from powder with a particle size of from 5 to 10 microns has a room-temperature hardness of 234 DPN, the corresponding value being 202 DPN for powder with a particle size from 15 to 25 microns. Hot-pressed compacted and sintered metal and hot-rolled, hot-pressed sheet have a room-temperature hardness of about 184 DPN. It has been observed that transverse hardness values are lower when measured in the longitudinal direction for unworked materials. At elevated temperatures, the hardness values found for sheet material fall from 184 DPN at room temperature to 126 DPN at 180°C, 112 DPN at 300°C, 84 DPN at 400°C, and 72 DPN at 500°C. Pure beryllium has a hardness value about one-third that of Q.M.V. powder (i.e., powder made from pebble with an intermediate vacuum-melting). The purity of the metal is controlled by the purity of beryllium fluoride and magnesium used in the process.

The ultimate tensile strength and elongation of beryllium in the form of extruded flake or extruded powder

at different temperatures are given in Table VI, in which it should be noted that the elongations quoted are in the preferred direction. Unless the material is upset-forged, elongation is likely to be 1% in other directions. Elongation diminishes above 800°C, and the useful range for its plastic deformation is thereby determined. High cutter speeds should be selected to yield shear-plane and interface temperatures within the ductile range of the metal. At cutting speeds of from 200 to 300 fpm, the metal machines with a brittle, discontinuous chip similar to cast iron. High positive rake angles (15 deg.), with relief angles of 5 to 8 deg., are recommended, together with a pronounced approach angle to increase chip-thickness ratio, to thin the chip, to reduce chipping tendency, and to improve tool wear.

TABLE VI: U.T.S. AND ELONGATION OF BERYLLIUM

Temperature [°C]	U.T.S. [tsi]	Elongation [%]	Condition
27	30	5	Extruded flake
27	40	16	Extruded powder
600	7	10·5	Extruded flake
600	10	8·5	Extruded powder
800	2·5	9·1	Extruded flake
800	3	10·5	Extruded powder

Particles of beryllium dust produce a toxic effect, so that touching, inhaling, and ingesting them must be avoided. In the finely divided form the metal can produce acute lung irritation and skin affections. It is therefore essential to provide effective barriers against atmospheric pollution (to within 2 micrograms/m^3) and this requires stringent safety measures. Thus, all machines must be completely enclosed, the enclosure being maintained at a lower pressure than that in the shop itself. Air extraction is provided at the chip/tool interface, and the operator manipulates the machine controls thorugh a glove-box, as shown in Fig. 9. In addition, protective clothing is worn in the contact area. This clothing must be changed completely before the operator leaves the area, a fresh set being supplied for each shift.

Fig. 9. Turning beryllium in an enclosed cabinet, showing air-extraction facilities and glove-boxes.
(Courtesy of Sir W. G. Armstrong Whitworth Aircraft Ltd.)

High-speed steel tools and carbide-tipped tools are employed for milling and turning at cutting speeds within the range of 200 to 400 fpm, and feed rate varies between 0·005 and 0·020 in./rev., the heavier feed tending to produce a roughened finish, especially at the lower limit of machining speeds—again a characteristic of the brittle nature of the material. Drilling is effected with 90-deg. carbide at cutting speeds from 10 to 100 fpm, with a feed of 0·005 to 0·010 in./rev., the drill being frequently withdrawn to prevent chip compaction.

Grinding needs especial care on two points, i.e., the toxicity of the dust and its very high strength and abrasive character in the finely divided form. The wheels selected must therefore tend towards medium (60-grit) and should break down freely to avoid loading, presenting fresh facets for the cutting operation. Aluminium oxide vitreous-bonded grades are found suitable.

The Machining of Molybdenum

Molybdenum, which has a specific gravity of 10·2, has a high Young's modulus (46×10^6 at 25°C, and 40×10^6 at 1000°C), a low specific heat (0·0624 cal/gm/°C at 20°C, and 0·0750 cal/gm/°C at 1000°C), and good thermal conductivity at room temperature and at elevated temperatures (0·382 cal/cm^2/cm/sec/°C at 20°C, and 0·259 cal/cm^2/cm/sec/°C at about 925°C). Molybdenum suffers a smaller reduction in strength with increasing temperature than solid tungsten, the modulus/density ratio of molybdenum being 4·5, as compared with 2·6 for tungsten. Molybdenum retains over 50% of its room-temperature strength at 1000°C, when its effective strength is 36,000 psi.

The material is sintered or arc-melted in a copper mould, this process being followed by a 2 : 1 reduction with interstage reheats at 1500 and 1200°C. Rolling is then accomplished at lower temperatures. Work-hardening occurs during reduction because, at the temperatures employed, recrystallization is sluggish. Conditions where the heating effect assumes predominance over strain-hardening are not reached at temperatures below 1800°C.

TABLE VII: U.T.S. AND ELONGATION OF (AS-ROLLED) PURE MOLYBDENUM AND OF MOLYBDENUM ALLOYED WITH 0·45% Ti

Temperature [°C]	Pure Molybdenum		Alloyed Molybdenum	
	U.T.S. [tsi]	Elongation [%]	U.T.S. [tsi]	Elongation [%]
27	45·7	40	50·5	29
650	31·1	24	45·2	18
875	23·2	24	38·8	17

Molybdenum-based alloys possess even greater hardness and resistance to forming at elevated temperatures. Additions are mainly made from aluminium, chromium, silicon, titanium, tungsten, and vanadium. Table VII shows the comparative ultimate tensile strengths and elongations at different temperatures of pure molybedenum and of molybdenum alloyed with 0·45% titanium, both materials being in the as-rolled condition. The ultimate tensile strength of a drawn wire of pure molybdenum, 0·05 in. in diameter, is 60 tsi, and its elongation is 5%. Smaller-diameter wires have higher strength and lower elongation.

Molybdenum machines with a discontinuous chip form, somewhat characteristic of more slowly machined hardened medium-carbon steel. Tungsten carbide tools are an obvious choice; high-speed tools are impracticable, their wear rate being accelerated by work-hardening of the stock and its low specific heat. The strain-hardening characteristic of the material demands that feed rates should be generous (0·010 to 0·015 in./rev.), and the depth of cut should be selected within the range of 0·010 to 0·125 in., leaving a minimum of 0·005 in. for the finish pass.

Carbide-tipped milling cutters can be employed in cutting at speeds up to 100 fpm. Single-point machining is found to be satisfactory with speeds of 150 fpm. The machine tool and fixtures require to be extremely rigid; otherwise, the tool and workpiece material will exhibit a chipping tendency. Low positive rake and relief angles appear to give the best results. A zero approach angle assists in avoiding chip thinning. Drilling of holes with a small depth/diameter ratio can be effected with high-speed drills. Deep holes require tungsten-carbide-tipped, thick-web, high-helix-angle drills. Cutting speeds of 30 to 40 fpm with a feed rate of 0·005 in./rev. are recommended.

Tapping must proceed with care, on account of chipping. Careful alignment and the use of heavily chlorinated oils or trichlorethylene mixes are recommended. Spiral flutes are an advantage. Sulphurized oils improve machinability, but they may have certain deleterious effects. Possibly, restriction of thread to 60% of full depth may be advisable.

Grinding, using a 60-grit aluminium oxide wheel, is found to be satisfactory. Hard wheels with a grit size finer than 80 load rapidly and require frequent dressing. Speeds normally used for grinding steel (6500 fpm) can be employed satisfactorily to offset work-hardening of the abraded surface. Bearing in mind the high shear strength of the metal at high temperature, the total energy per unit of stock removed must be correspondingly high, so that the set depth of grinding must be on the light side and the width of each pass adjusted accordingly. For the cylindrical grinding of molybdenum to a surface finish of from 10 to 30 micro-inches, the recommended infeed per pass is from 0·0005 to 0·0010 in. and the work speed 1000 fpm. For the surface grinding of molybdenum to a similar surface finish, the recommended infeed per pass is from 0·002 to 0·005 in., with a table speed of 50 fpm and a cross feed of 0·03 in.

The Machining of Titanium

Titanium and its alloys possess many advantages which make them competitive in the field of chemical engineering and aircraft construction. The room-temperature strength of wrought alloys is of the order of 60 to 73 tsi. It is relatively light (specific gravity = 4·51). The aluminium-manganese alloy (Ti-4Al-4Mn) can be worked and heat-treated within limiting sections to exhibit a fatigue resistance equivalent to that of a high-tensile steel. The diminution in strength with temperature rise is substantially linear up to 400°C, when some 30% is lost. In the range of 500 to 550°C, the 1% proof stress is maintained at 28 to 30 tsi. Titanium and its alloys have a relatively low modulus (15×10^6 psi), which diminishes at temperatures above 300°C.

Most titanium alloys exhibit pronounced work-hardening characteristics. At temperatures above 650°C, the metal commences to absorb intersitially and, although with the more pure forms of titanium sponge small quantities of carbon and oxygen may prove to be beneficial strengtheners, strength is generally improved at the expense of notch sensitivity. Nitrogen and oxygen effect a reduction of the slip and twinning systems available for deformation. Hydrogen creates marked embrittlement and increases the detrimental effect of the alpha-seeking interstitials.

Most of the difficulties concerned with the machining of titanium arise from a pronounced tendency to gall and to work-harden. Galling is a characteristic of the metal, while work-hardening is a characteristic of impurities in the melt, although hardening is greatly accentuated by the presence of the substitutional alloys. Galling promotes chip weldment and rapid build-up on the edge of the tool. The low values of conductivity k, of density ρ, and of specific heat c precipitate this situation.

Since the total energy u expended in the chip-forming process is approached at high cutting speeds by the value u_c of the division of energy carried away by the chip,

$$u = u_c = u_s + u_f$$

where u_s and u_f are the shear and friction energies respectively. Consequently,

$$u_c = R_1 u_s + R_2 u_f$$
$$u_t = (1 - R_2)\, u_f$$
$$u_w = (1 - R_1)\, u_s$$

where R_1 and R_2 are the ratios of division of shear and friction energy, and u_t and u_w are the divisions of energy remaining with the tool and the workpiece respectively. For those metals possessing good ($k\rho c$) values, the higher is the machining speed the more nearly does u_c approach the total energy u, so that the heat energy absorbed by the tool is relatively small. Low ($k\rho c$) values appertaining to the machining stock dictate that the interface temperature will rise and more energy will be imparted to the tool. Diffusion and plucking will result, and the tool will break down rapidly. The development of the argument has ignored u_w, but it will be seen that u_w can be lumped with u_c, as it possesses identical conductive or refractory characteristics.

The problem of energy distribution at the chip/tool interface is present with all refractory metals. Titanium and its alloys, however, will react at high temperatures to form abrasive surface carbides and oxides. Tukon hardness tests on chip sections reveal localized increases in DPN values of from 320 to 600.

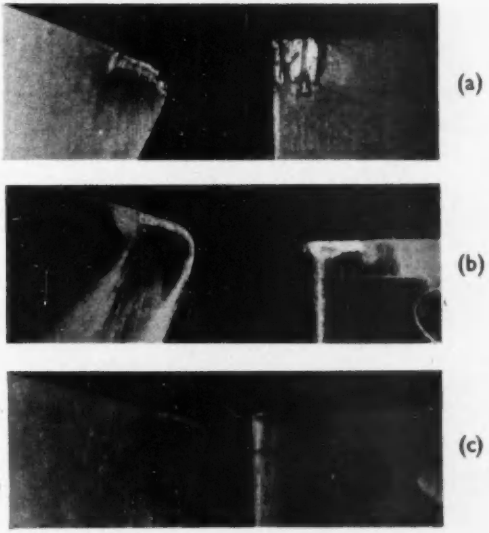

Fig. 10. Comparative wear experienced when machining Ti-4Al-4Mn alloy at a cutting speed of 90 fpm, (a) on a general-purpose titanium carbide tool after producing a chip length of 1050 ft, (b) on a steel-grade titanium-tungsten carbide tool after producing a chip length of 2310 ft, and (c) on a cast-iron-grade tungsten carbide tool after producing a chip length of 2310 ft.

The avid nature of titanium promotes the migration of binder material from carbides and leads to calamitous tool wear. High-speed tools fail from crater wear at lower cutting speeds, and therefore cannot be employed at speeds exceeding 50 to 80 fpm for commercially pure titanium, while alloys of sufficient strength reduce this speed to 25 fpm and below. To produce consistent performance, tools require a generous nose radius (0·25 in.), a positive side rake (10 deg.), and a 5-deg. relief minimum at rubbing faces (front and side cutting-edge clearance angle). Thinning the chip by the use of a large approach angle is found to be beneficial. Soluble oils in a 3 : 1 mix or inhibited-type oils are essential to prevent diffusion and abrasive wear in the manner described. Milling cutters follow the practice defined for single-point tools; a radial rake of 10 deg., and 7-deg. side and top relief angles are required.

Essentially, however, titanium alloys should be machined with a hard-grade tungsten carbide, as metallic carbides with tungsten produce indifferent results. Titanium carbide appears to cause self-diffusion, and the breakdown of the tool is precipitate, as shown in Fig. 10. Cutting speeds selected in the range between 80 and 120 fpm will produce satisfactory tool life and good surface finish. At 150 fpm, tool life is significantly reduced, and breakdown becomes more precipitate with a further increase in cutting speed. It should be noted, however, that tool life can be increased by a factor of at least 2½ if, in conjunction with CO_2 cooling, machining is carried out under an argon atmosphere.

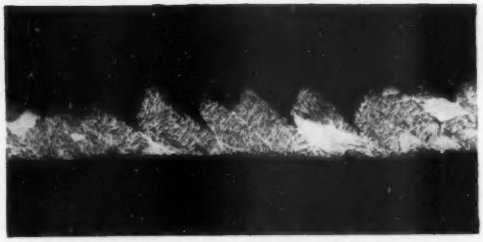

Fig. 11. Photomicrograph of a titanium chip, showing alpha lamellae dividing adjacent rigid areas, which exhibit an undisturbed alpha-beta matrix.

Fig. 11 shows a photomicrograph of a titanium chip, illustrating the relatively wide shear-plane spacing and rigid body characteristic of the metal between the shear

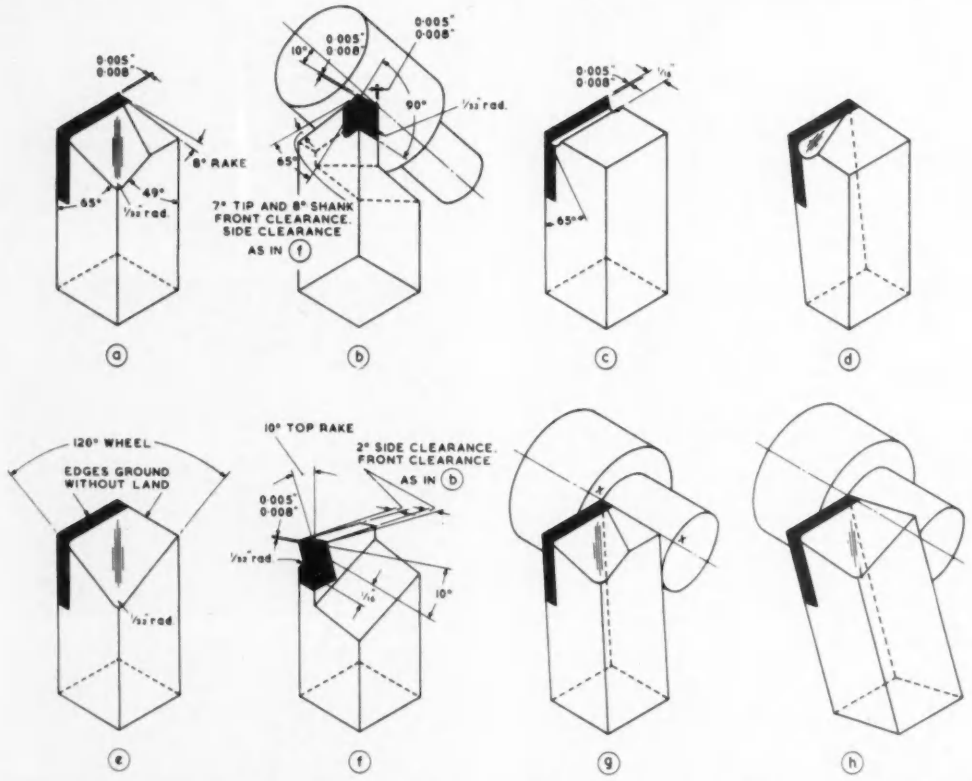

Fig. 12. Optimum tool geometry for tangential knee-turning tools, roller-box tools, and part-off tools when cutting titanium 150A and Ti-4Al-4Mn on a Wickman 1-in., 6-spindle automatic.

(a) Geometry for a tangential knee tool for cutting titanium 150A.
(b) Geometry for a part-off tool for cutting titanium 150 A.
(c) Grind on a tangential tool, resulting in crimping of the swarf and edge breakdown.
(d) Grind on a tangential tool with a narrow chip groove, resulting in crimping of the swarf and welding it together, causing edge breakdown.
(e) Geometry for a roller-box tool for cutting Ti-4Al-4Mn.
(f) Geometry for a part-off tool for cutting Ti-4Al-4Mn.
(g) Tangential tool with side edge parallel to the axis of rotation.
(h) Roller-box tool with side edge inclined to form an 8-deg. negative rake angle.

planes; it will be seen that the alpha-beta basket-weave structure is barely disturbed. The metal affords excellent corroboration of the Piispänen theory of chip formation*. Ferrous metals have an entirely different chip microstructure, tending to make the Piispänen concept hypothetical.

Little published work is available relating to the machining of titanium alloys on automatics. Fig. 12 shows the tooling for a Wickman 1-in., 6-spindle automatic, which combines the results of basic investigations into the machining of I.C.I. 314A (Ti-4Al-4Mn) alloy, to establish machinability at full product development of available titanium alloys.

There appears to be considerable difficulty in tapping and thread-rolling titanium. The use of straight-fluted taps with full thread relief and cutting a truncated thread form with initial taps have been found to be the solution. A cutting-edge rake of from 5 to 8 deg. is essential, and the central web needs to be thick. Additionally, torque loading during tapping has in some cases been reduced by the omission or restriction of the number of teeth formed on the tap. Thread rolling requires the use of rigid equipment; otherwise, the crests will fail to form and the flanks will harden, showing cracks in the surface microstructure.

Grinding demands the use of a wheel which will break down in a controllable manner, presenting as it does so fresh facets with which to cut. Concurrently, the low ($k\rho c$) values of titanium demand that the grinding speeds selected should be approximately one-quarter of those employed for the grinding of steel. Assuming that the total energy absorbed in the cutting forces at speeds above 800 fpm, the dimension of the swarf, the value of shear strain, and the residual strain remaining in the unit volume of chip are identical, it can be shown† that the respective grinding speeds V_s and V_t for steel and titanium bear the relation

$$\frac{V_s}{V_t} = \frac{(k\rho c)_s}{(k\rho c)_t}$$

Thus, for steel, with $k = 4{\cdot}8 \times 10^{-4}$, $\rho = 0{\cdot}28$, and $c = 0{\cdot}20$, the value of $(k\rho c)$ is 27×10^{-6}. For titanium, with $k = 2 \times 10^{-4}$, $\rho = 0{\cdot}16$, and $c = 0{\cdot}10$, the value of $(k\rho c)$ is 6×10^{-6}. Consequently, for the same interface temperature, the grinding speed of titanium in relation to steel ground at 6000 sfpm will be $6000 \times 6/27 = 1330$ sfpm approximately.

Confirming this calculation by practical application, it is useful to note that Norton have recommended a grinding speed of 1300 sfpm as suitable for the Ti-4Al-4Mn alloy, when using aluminium oxide wheels. Silicon carbide wheels can be run at spindle speeds between 2500 and 3500 rpm with a reasonable wheel life, provided that straight grinding oils are used. Aluminium oxide wheels perform best with nitrate-amine solutions.

Performance is measured in terms of the grinding ratio G, i.e., the ratio of the volume of stock ground away to the loss of volume of the wheel. Poor combinations result in G-values of 2, while good combinations yield G-values of 26, approximating those obtained when grinding steels. Swarf from coarser wheels has a lower total energy but fine wheels are needed for thread-grinding and good surface finish. Aluminium oxide wheels of 60 to 80 grit are found suitable for general-purpose work and will yield a surface finish of from 10 to 14 micro-inches, while 150-grit wheels produce the best surface finish, values of from 6 to 8 micro-inches being obtained.

The Machining of Nimonic Alloys

The incorporation of 18% cobalt in Nimonic 90 and 95 is made to improve creep properties. Nimonic 100 has less chromium, but the cobalt is increased to 20% with a 5% molybdenum addlition to improve high-temperature properties in the range between 950 and 980°C. Chromium and cobalt together produce a more difficult problem in machining, compared with the early series of Nimonic alloys. The hardness of the fully heat-treated wrought material varies, values for Nimonic 95 being from 300 to 360 DPN, and for Nimonic 100 from 320 to 420 DPN.

A complex carbide mix, Teco CL, was found to give the best performance in cutting Nimonics. Cutting speed and chip-thickness ratio r_t require to be held to low values, to avoid all modes of frictional wear at the tool face. Suitable cutting speeds yielding a tool life of 1 hr (estimated as 0·015 in. flank wear) have been found to be of the order of 50 to 60 fpm, with $r_t = 0{\cdot}436$. Tool life is reduced to 7 min at 100 fpm, with $r_t = 0{\cdot}5$. Low positive rake angles are indicated, to reduce sliding speed and to provide for the characteristic of high strength with temperature of the metal.

At a cutting speed approximating 80 fpm, a mean interface temperature of 650°C is reached, approaching the precipitation temperature of the metal. A small reaction has been noticed at this point when CO_2 cooling is employed, indicated by a rise in temperature of 15°C, and it is possible that a precipitation-hardening mechanism may be activated. This observation has been found to persist throughout the range of temperatures up to 760°C, but tool life is not noticeably affected.

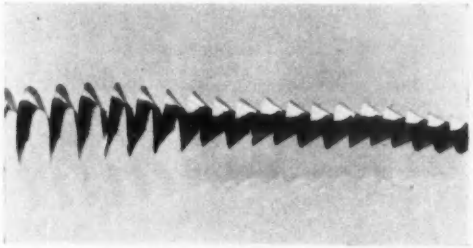

Fig. 13. A chip of Nimonic 100, the chip thickness remaining virtually constant at 0·015 in., although the infeed varies from 0·1 to 0·5 in.

Under suitable conditions, the Nimonics machine with a clean, continuous chip and are remarkably consistent in chip-thickness ratio and shear-plane spacing, irrespective of the depth of cut. Fig. 13 illustrates a Nimonic 100 chip produced by a variation in set depth at a constant feed rate during a contouring sequence; the chip thickness was found to vary less than 0·001 in. at any position.

Grain size is found to produce an effect on tool life. Materials possessing corresponding hardness values throughout their respective cross-sections, but having average values of 200 and 300 grains/in. respectively, produced a variation in rate of flank wear of 3 : 5, the coarser grain permitting longer tool life.

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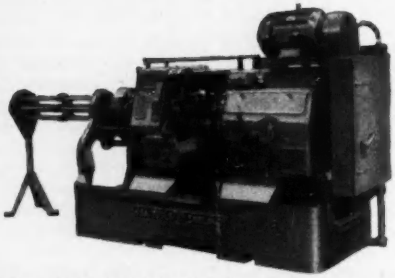
* V. PIISPÄNEN: *Teknillen Aikakauslaht*, Vol. 27, 1937, pp. 315-322.

† W. S. HOLLIS: "*The Machining of Titanium Alloys*"; Conference on Technology of Engineering Manufacture, Inst. Mech. E. Paper 10, 1958.

B·S·A production machines



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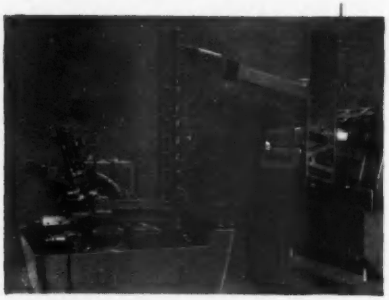

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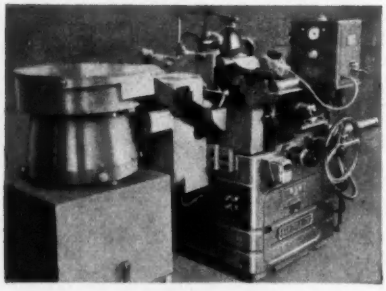

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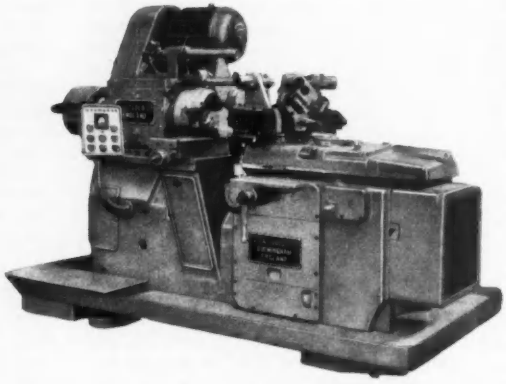
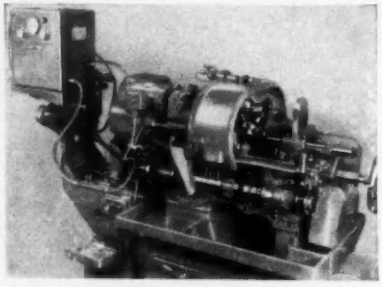


B.S.A. No. 95 All-Electric single-spindle automatic chucking machine with "DISCOTROL" programme control unit. (Complete machining programme for a component recorded on a master disc). Immediate changeover effected by substituting a new programme disc and appropriate tooling. Re-setting of machine speeds and feeds eliminated. Highly sensitive overload device protects tooling. Five-face turret. Swing over cross slides $10\frac{3}{4}$" (maximum swing $12\frac{1}{2}$"). Stroke: of cross slides 4", of turret $5\frac{1}{4}$". Thirty spindle speeds: 40 to 834 or 60 to 1220 r.p.m.



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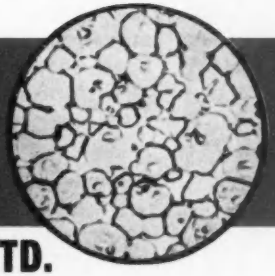

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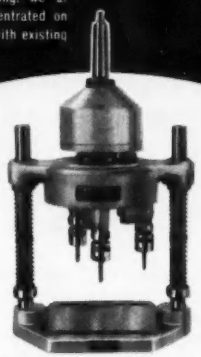

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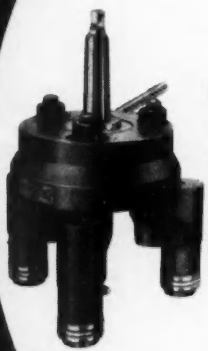

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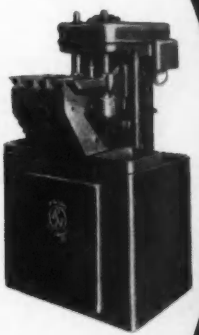

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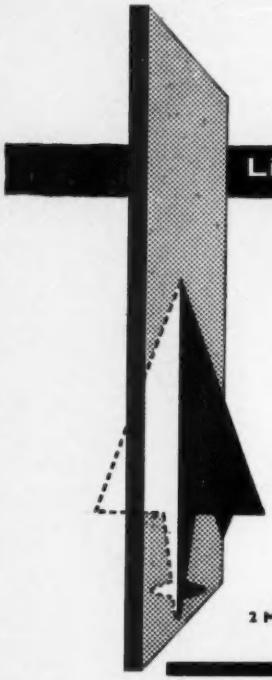

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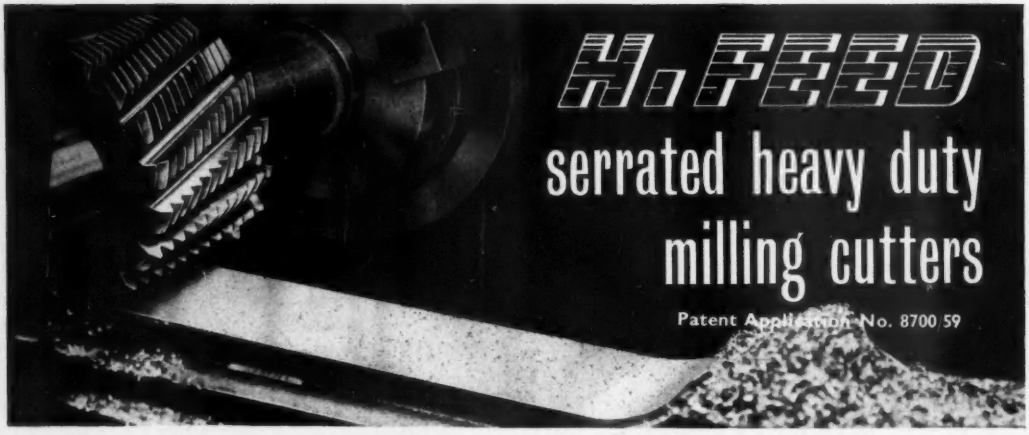

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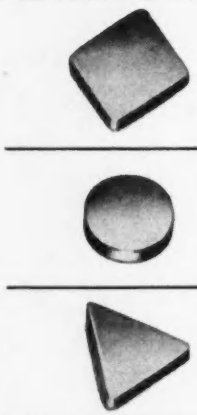

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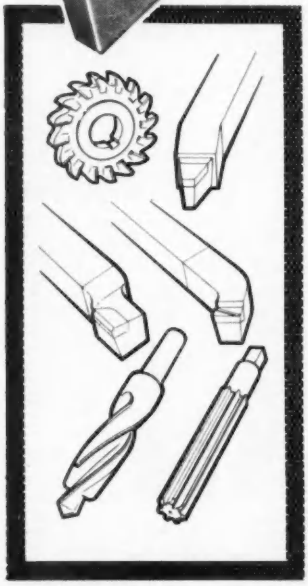

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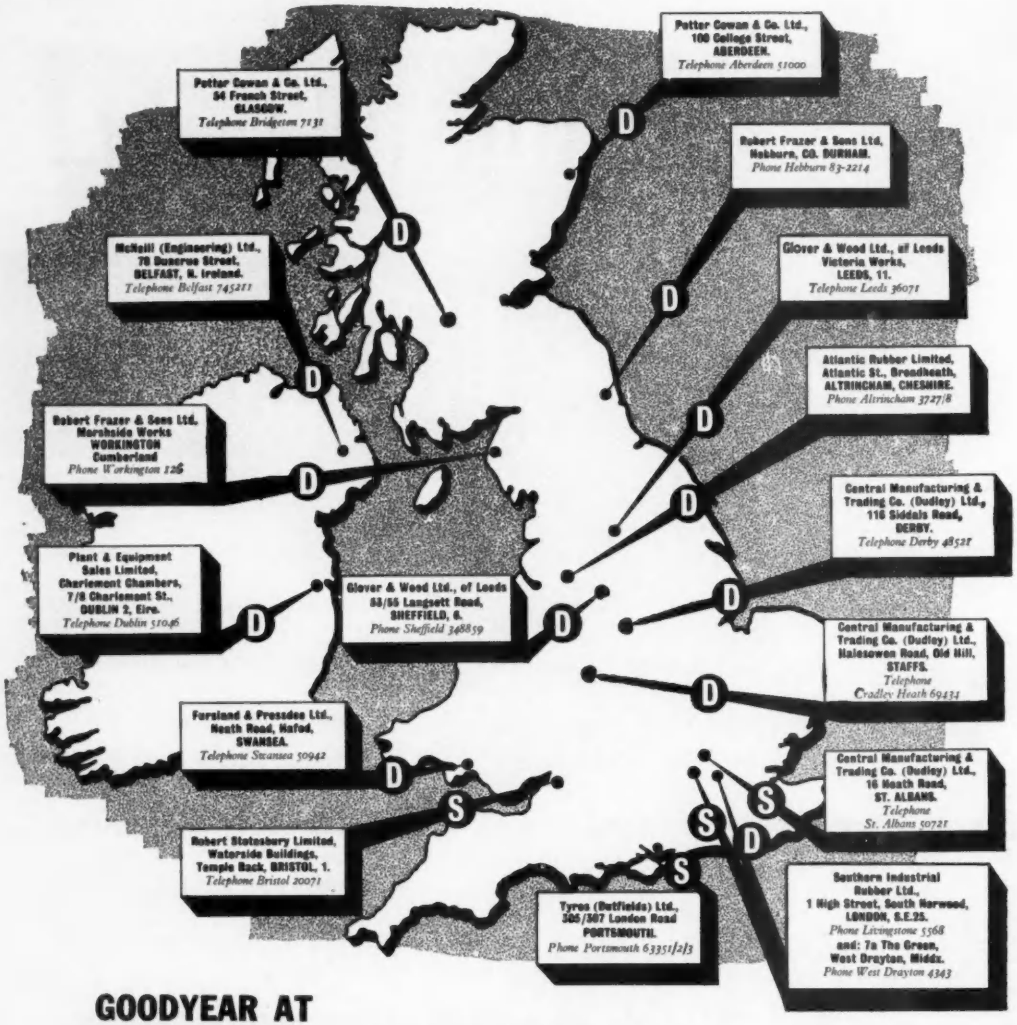
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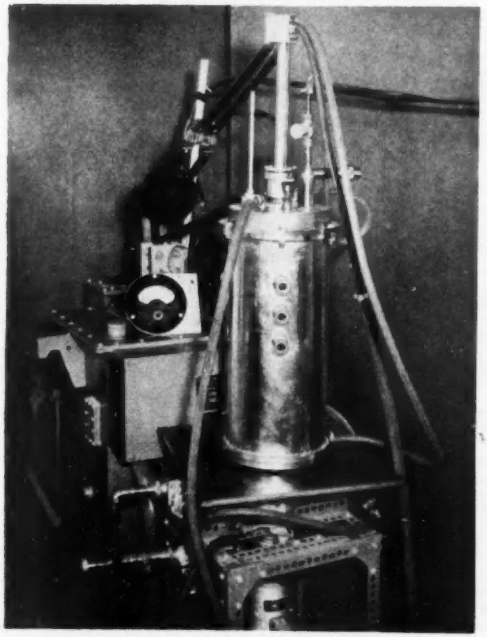
THE GREATEST NAME IN RUBBER

British Industrial Developments

High-Temperature Vacuum-Permeability Rig for Graphite Fuel-Cans

A rig for determining the vacuum permeability of graphite fuel-cans at various temperatures up to 2300°C and under varying tensile loads has been designed and manufactured by Spembly Ltd., of Chatham, a member of the Harper Group of Companies, in conjunction with, and for, the U.K. Atomic Energy Authority.

The main vacuum shell consists of a water-cooled, stainless-steel cylindrical body mounted on an oil diffusion pump, backed by a single-stage rotary vacuum pump. Three sight-tubes, fitted with clear fused-silica windows, are spaced down the body and pass through a water jacket. A flanged ring, carrying a flat spiral copper water-cooling coil, is fitted between the vacuum body and the diffusion pump. On this coil are mounted the bottom radiation shields, one each of copper, molybdenum, and tantalum in that order. Three tubular concentric radiation shields, two of molybdenum and one of tantalum, run the length of the vacuum shell, the spacing between the cylinders being maintained by ceramic sleeves over tantalum bolts. The three top radiation shields are of the same material in disc form and fit into the staggered ends of the cylindrical shields.



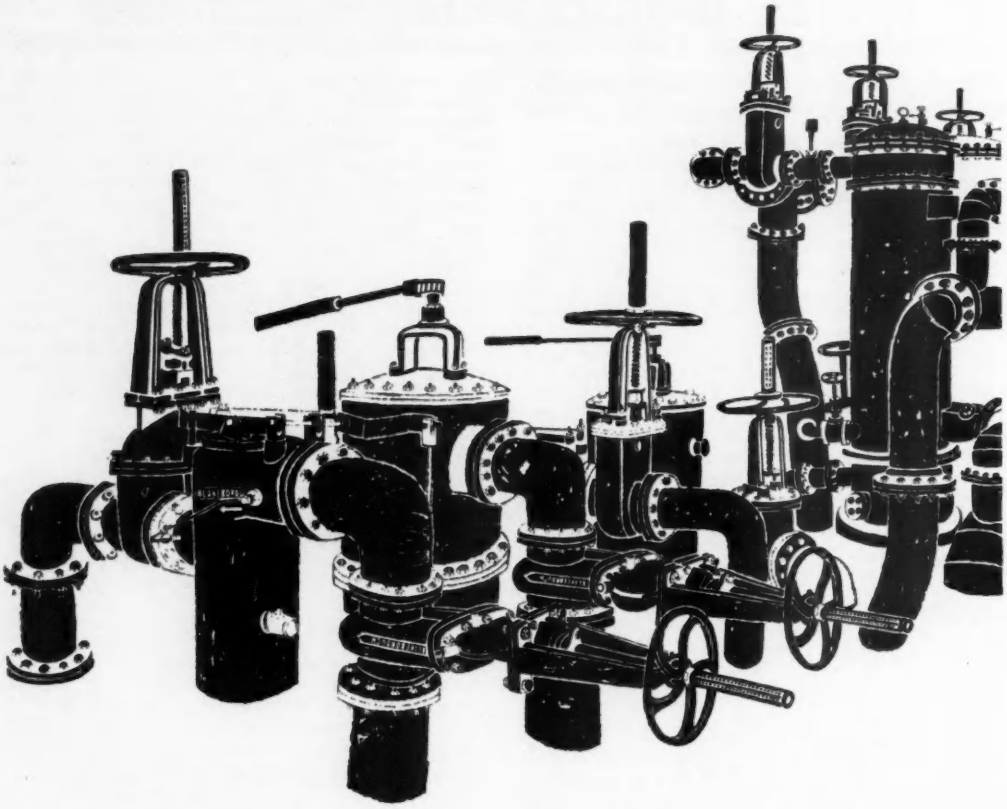
The top, or lid, of the apparatus is of stainless steel, water-cooled over its entire area. Through the water jacket are passed service tubes for vacuum or gas admittance to the vacuum shell, and for mass-spectrometer connections. Two rotary vacuum seals are fitted, the shaft of the larger being hollow and fitted with thermocouples. The smaller shaft carries three spaced stainless-steel discs, operation of this shaft moving the discs over the apertures of the sight tubes to prevent vacuum deposits on the windows. The specimen of graphite can is held in position in the centre boss of the top lid by means of a screwed collar, which forces a split copper cone onto the specimen and its cone seating, thus providing good electrical contact. A central temperature-profiled rod of graphite runs down through the specimen onto a cone seating in its blind end. To the central rod is screwed a thick-walled, water cooled copper tube which extends out above the apparatus. Around the copper tube is a further tube of stainless steel running into an insulated O-ring gland in the top lid, both tubes terminating in a brass block. This block carries the water inlet and outlets for the central rod extension, and also the helium or hydrogen gas inlet to the stainless-steel tube. Provision is made on the block for busbar attachment.

The power supply to the apparatus is by a 240-V, single-phase transformer, with an output of 30V, 1200A, operated by a saturable reactor with d.c. control via a variable resistor. The supply is fed in through the brass block, down the thick-walled copper tube and the centre rod to the blind end of the specimen, and thence up the specimen wall and out through the casing. Temperature control of the specimen is effected either by thermocouples in the low range or an optical pyrometer in the higher ranges. When the required temperature is reached, helium or hydrogen is forced under pressure into the hollow specimen via the stainless-steel tube. The quantity of gas permeating through the graphite can then be detected by mass-spectrometer methods. By varying the power and the force applied to the brass block, a range of values of permeability for the specimen can be obtained for temperatures up to 2300°C and at various tensile loadings.

Continuous Wire-Patenting Furnace

The latest wire-patenting installation at the Doncaster works of British Ropes Ltd. is a 700-kW furnace designed by Efco Furnaces Ltd., of Weybridge, Surrey, in conjunction with British Ropes Ltd. Used for heating rod prior to quenching in a lead bath, the furnace has an open-type chamber accommodating 32 rods positioned by guide-blocks at both ends. Special precautions have been taken to avoid damage to elements and furnace brickwork when hooked joints in the rods pass through the chamber. Thus, the hearth and walls of the furnace are made of a hard non-scoring firebrick, while the elements in the loading section of the furnace, where the rods may not lie flat, are protected by heavy guards suitably shaped to prevent the hooked ends from catching on them.

The furnace chamber is 78 in. in width and has a heated length of 90 ft. The heating elements are of nickel-chromium strip, formed into a hairpin shape and mounted in the roof, and can be easily withdrawn for maintenance purposes. The elements are arranged in six independently controlled zones, each of which is supplied by a separate step-down transformer and has its own automatic temperature controller and recorder. To meet the stringent metallurgical requirements involved, special attention has been paid to the electrical loading of the individual zones, to the heat distribution



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More than £1,360 saved in a year at J. Blakeborough & Sons Limited

TAKING POSITIVE ACTION to cut maintenance and lubrication costs, J. Blakeborough & Sons Ltd., world famous valve manufacturers, consulted the experts—Mobil. After accepting their recommendations, and applying the correct lubrication programme, Blakeborough found that they had made direct savings of over £1,360. Indirect savings were estimated at a further £2,100.

World-wide experience of industrial lubrication

This example of the value of Mobil Economy Service is typical of many that could be cited from almost every industrial area of the world. In all these areas, the world-wide Mobil organization is applying more than 90 years' experience to the cutting of lubrication and maintenance costs.

One plan to meet all lubrication needs

The value of Mobil Economy Service is the value of expert knowledge methodically applied: it is a matter of assessing all the lubrication needs of a business collectively; considering how they can best be met with the fewest different lubricants in the smallest quantities; and making sure that everyone concerned knows how to use the lubricants to the best effect with the absolute minimum of work. The astonishingly large savings that are often achieved are the measure of the experience and skill that Mobil bring to the consideration of every lubrication problem.

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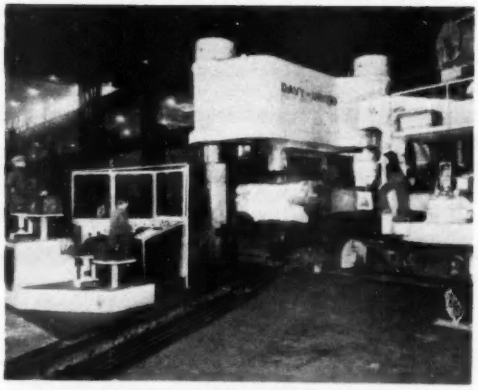
necessary to provide a uniform temperature across the width of the furnace, and to accurate control along the whole length. The transformers supplying the individual zones are so designed that the power rating can be adjusted to give the fine control required. A further feature is that, after initial start-up or after operating the furnace at a reduced work output, the power distribution can be modified by means of a change-over switch on the control panel. In this way, more power is provided towards the inlet end of the furnace, enabling an increased output to be obtained. To conserve floor space, the electrical control gear, including transformers, switchgear, and temperature controllers, is installed in a penthouse in a central position above the furnace. Access to this penthouse, which is more than 40 ft in length and 11 ft in width, is provided by a stairway at one side of the furnace.

3000-Ton Two-Column Forging Press

Making it possible to undertake the work previously required by three presses, the new 3000-ton forging press installed at the works of Walter Somers Ltd., of Halesowen, near Birmingham, is a two-column, oil-hydraulic, three-stage, draw-down unit, with three hydraulic working cylinders in line. As compared with conventional four-column designs of press, the two-column inverted design confers a number of advantages, including a saving in height, better access to press tools, and improved stability. In addition, the view of the operator is improved, there is less risk of fire, and the housing of electrical and pumping equipment is more compact.



The press can be used with an effort of 1000 tons and a press speed of 7·5 ips, 2000 tons with a press speed of 3·75 ips, or at its maximum thrust of 3000 tons with a press speed of 2·5 ips. The approach speed is 9 ips, and the return speed is 14 ips. The press columns are set at 14-ft centres on a centre-line at an angle of 30 deg. to the centre-line of the sliding anvil, giving the operator a completely clear view of the work under the press. There is 12 ft of daylight between the top moving crosshead and the sliding anvil plates, and the press stroke is 7 ft. The anvil is carried on hydraulically powered sliding plates, and the complete bottom tooling with the forging in position can be moved a total distance of 14 ft, or 7 ft each side of the working centre-line. The press is fitted with tool-change gear, enabling a complete set of tools to be changed in a matter of minutes. Six pumps are provided, these being driven in pairs by motors with a nominal rating of 500 hp each, with a peak power of 1000 hp at a working pressure of 4500 psi. The pumps, each of which delivers 150 gpm of oil at 1500 rpm, are installed in the foundations below the press, as also is the hydraulic valve gear for controlling the working tonnage and the stroke of the crosshead and tools.

The control desk is located square with the press anvil, permitting an uninterrupted view of the forging. Immediately behind the control desk are located special controls, of a type developed by B.I.S.R.A., for three overhead cranes of 30, 60, and 100 tons capacity respectively. In addition to the cranes, an independently controlled floor-mounted 13-ton manipulator, for handling certain types of forgings, is installed. A maintenance panel is located at some distance from the press and serves to indicate whether the motors, pumps, and ancillary equipment are operating satisfactorily.

Industrial Level Controller with Two Electrodes

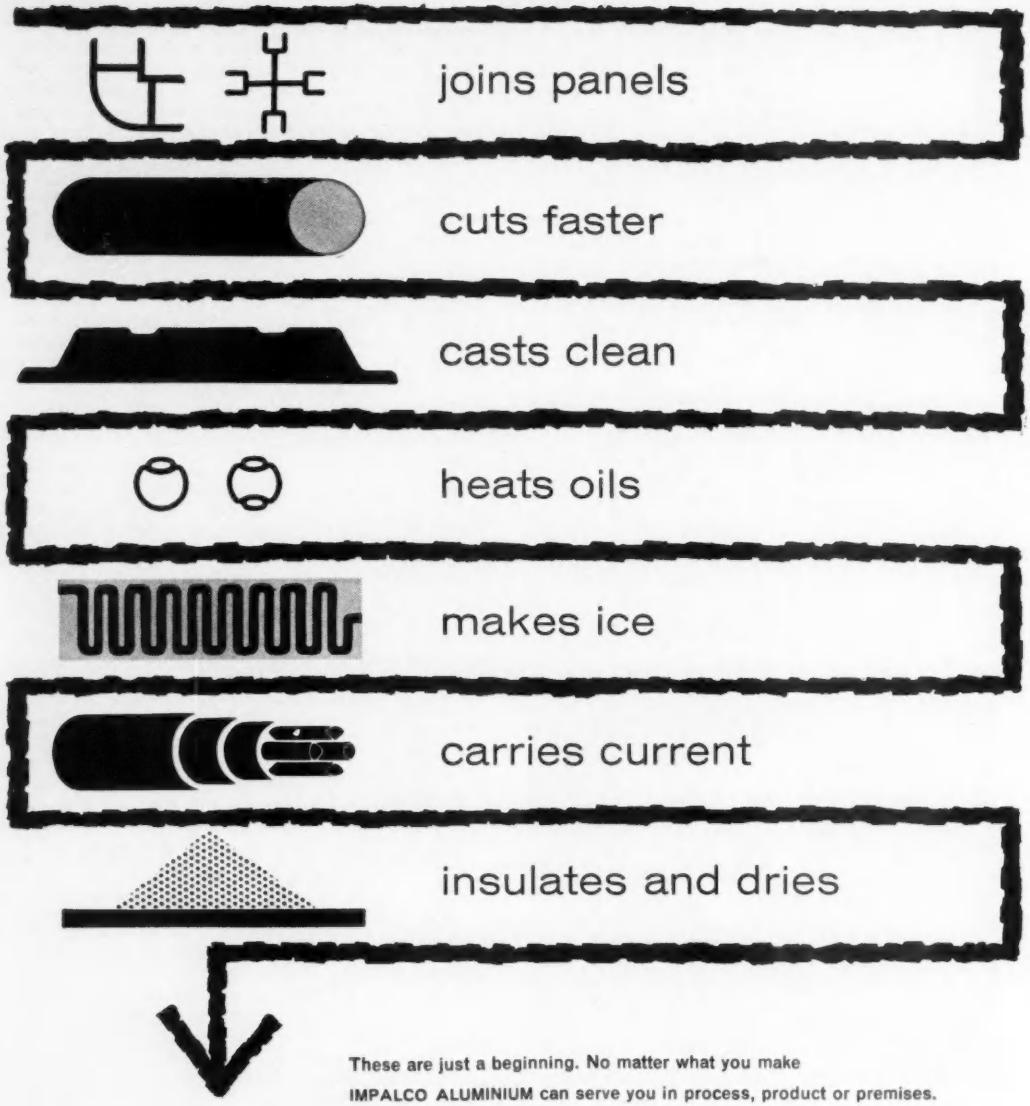
A new version of their "Leveltron" industrial level controller is announced by Thomas Industrial Automation Limited, of Altrincham, Cheshire, for use with two electrode units, one mounted at a high-level position and the other at a low-level position in a vessel, tank, or silo. The instrument can be used with any of the company's standard range of electrodes, and the distance from the controller to the electrodes can be as much as 50 ft.

The control unit has only one relay, which is de-energized when the high-level position is reached by the material involved, and is re-energized when the material falls below the low-level electrode, providing an automatic interlock between the two levels. Special contacts are fitted to the relay and serve to switch the electrodes into the circuit as required, so that, in effect, only one unit is required for both the high-level and low-level control of pumps, conveyors, valves, etc.

Supersensitive Radio System of Personnel Location

Radio systems of personnel location are recognized as efficient methods of getting into touch with mobile staff instantly and individually, without disturbing others. The basic principle of these systems involves the use of a small lightweight receiver carried in the pocket and, as soon as the receiver emits a given signal, the person concerned proceeds to the nearest telephone and announces his identity to the telephonist for further action. Several systems of this type are in use, but the outstanding feature of the system developed by Hasler Limited, of Berne, Switzerland, is the extreme sensitivity of the receivers used, resulting in economy of the loop aerials normally used to radiate the energy supplied by the transmitter. In fact, tests have shown that, with the Hasler system, one loop around a large modern hotel of steel construction at the first- or second-floor level provides effective coverage throughout nine floors above ground level and three basements, as distinct from other induction systems, which require at least four loops for the same coverage.

In the Hasler system, which is now being distributed in the U.K. by Tele-Nova Ltd., of London, S.W.1, the Electronics Division of the British Home & Office Telephone Co. Ltd., transmitters are available for either 20, 56, 90, or 380 separate channels and can be integrated into a private automatic telephone system, so that un-



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answered telephone calls can be automatically diverted to the pocket receiver and answered by the person called, who dials a predetermined number on the nearest internal telephone, connecting him instantly with the person calling, without the intervention of a third party. A variable signal distinguishes whether the call is made by the telephone operator or through the internal telephone system. The receivers are powered by batteries with an operational life of about one year, and the signal emitted can be heard clearly above ordinary industrial noise and has adjustable volume. For use in boiler-rooms and areas of excessive noise, a special model is available. The receiver has an attractively designed case of semi-pliant plastic and measures only $3\frac{1}{4} \times 2 \times 1$ in., its total weight being less than 6 oz. The control panel, which is normally sited with the telephonist, can be duplicated, if required. In this case, there are two sources of transmission, each with its own particular signal, so that the user of a receiver knows from which station the signal has originated.

Slide-Way Scrapers for Machine Beds

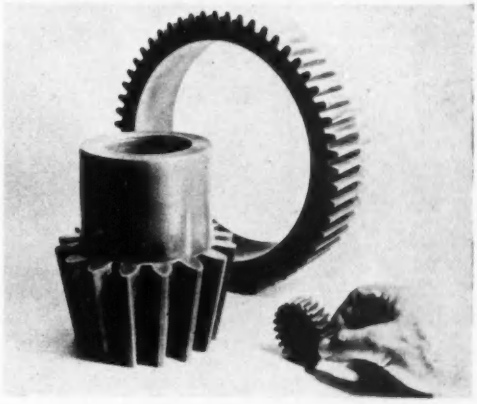
Designed for use wherever metal carriages, tables, or arms slide over machine-tool beds, rails, columns, etc., the range of slide-way scrapers announced by Vulcascot (Great Britain) Ltd., of London, N.W.8, provides positive protection against shavings, chips, abrasives, dirt, and other harmful materials. Their design is such that they ensure extremely accurate fits, so that harmful materials are prevented from being deposited either on the lip of the scraper or from being carried behind the heel to cause damage to metal beds, etc. Furthermore, they are resistant to water, oils, acids, and alkalis, possess great flexibility and abrasion resistance, and have a long and dependable service life.

These scrapers are precision-moulded from synthetic rubber and are available in four basic types. Of these, Type *A* is spring-loaded and metal-encased, while Type *B*, which incorporates a bonded metal strip for drilling accurate screw holes, is more flexible and is intended for curved and contoured surfaces. Type *C* is of plain synthetic rubber and is particularly adaptable for use in circular applications, while Type *D* incorporates a bonded finger spring and is also designed for use on columns and other circular applications. All four types are supplied in manufactured lengths of 22 in. and can easily be cut to the required length and drilled for attachment to sliding members by means of bolts or screws.

The "Monomer-Casting" Process for Producing Massive Nylon-Shapes

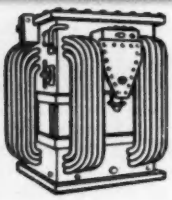
It is announced by Polypenco Ltd., of Welwyn Garden City, Herts., that, through their parent company, The Polymer Corporation, of Reading, Pa., they have acquired the exclusive rights to use in the U.K. and many other countries a new process which makes it possible to produce finished nylon parts of considerable mass. Designated "Monomer Casting", the new process, the basic chemistry of which was discovered by the Monsanto Chemical Company, and which is the subject of numerous patent applications by Monsanto, converts monomeric raw material directly to finished nylon parts at atmospheric pressure. The monomer, which becomes a mobile liquid, fills the recesses in the mould and polymerizes to a solid uniformly without forming vacuum bubbles, thus permitting the casting of complex components of far larger dimensions than have hitherto been possible.

In conventional techniques, the nylon is moulded into finished form from granules of powder previously polymerized in large-scale chemical operations. In the monomer-casting process, five steps required in conventional methods of manufacturing moulding powder are eliminated, and the cost of the raw materials is considerably reduced. The material used, designated MC nylon, is a Type-6 nylon formulation, but exhibits physical properties which span the range of properties available in nearly all nylons at present in industrial use. It should also be noted that the need for expensive moulds, such as those required in conventional injection or extrusion moulding, is eliminated. Thus, for instance, the cost of a monomer-casting mould for producing a component weighing about 7 lb at atmospheric pressure should be not more than 10% of that required for an injection-moulded part of the same weight at pressures up to 20,000 psi. It must, however, be appreciated that the monomer-casting process will not compete with injection moulding for the mass production of small parts, where mould costs are relatively low and injection cycles are as short as from 15 to 30 sec, as monomer casting would require a minimum of about 5 min per unit.



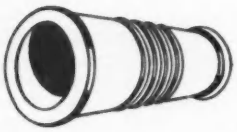
Although the new process uses techniques similar to those used in casting metals, there are certain differences. Thus, the moulds for monomer-cast nylon must be non-porous, because of the low viscosity of the monomer. Consequently, sand moulds cannot be employed, though permanent moulds can satisfactorily be made of metal, glass, or ceramics. Also, careful chemical and temperature control is essential, as the nylon solidifies by polymerization, as distinct from cast metal parts, which solidify by heat loss.

Castings made from MC nylon are stated to cost substantially less than comparable stainless-steel or brass castings and to compete favourably with alloy steels. It is expected that, in the next few years, increasing volume and production economy should reduce the costs to about 50% of the present level, making MC nylon competitive with carbon-steel and aluminium castings. The largest monomer-cast nylon parts so far produced have been semi-finished symmetrical shapes in the 500- to 700-lb range, equivalent to a weight of 2 tons for a steel casting of the same size. Theoretically, however, there is no technical limitation to the size of part that can be made by the new process.



from transformers

to bellows



the relief of stresses demands

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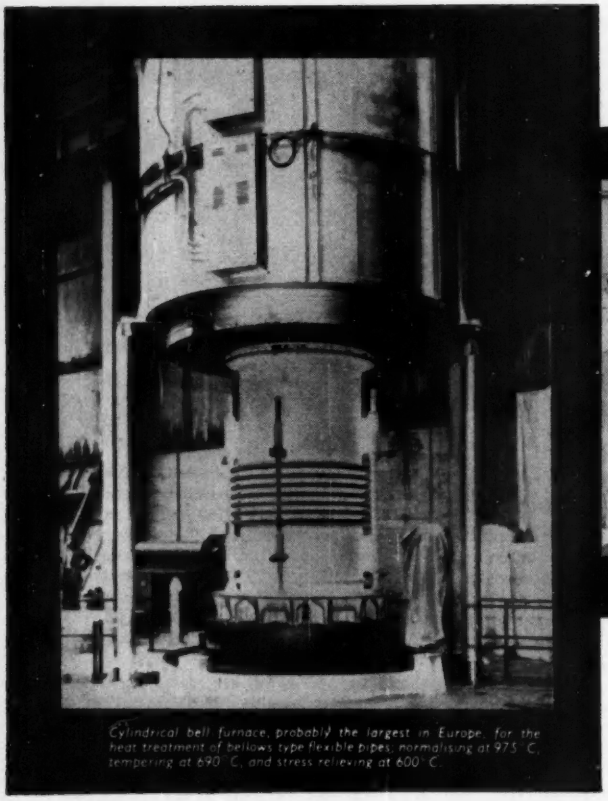
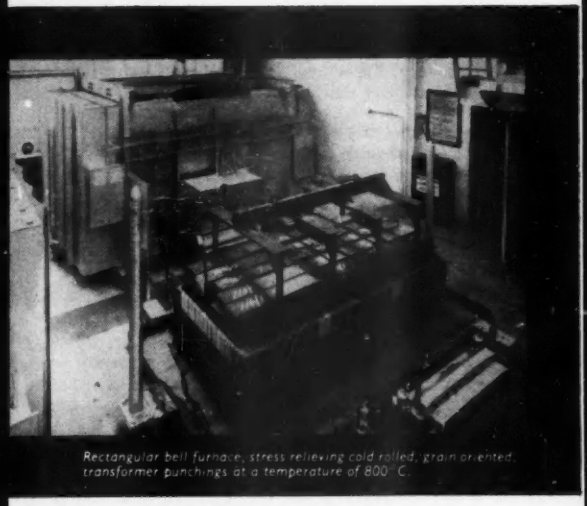


Cylindrical bell furnace, probably the largest in Europe, for the heat treatment of bellows type flexible pipes, normalising at 975° C, tempering at 690° C, and stress relieving at 600° C.



Rectangular bell furnace, stress relieving cold rolled, grain oriented, transformer punchings at a temperature of 800° C.

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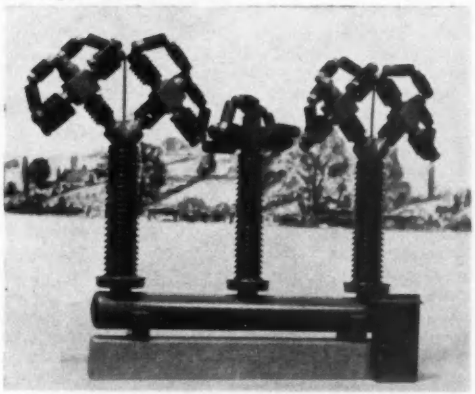
High-Performance Air-Blast Circuit-Breakers

To cater for world requirements for circuit-breakers with a very high performance at the highest voltages, The English Electric Co. Ltd. have developed air-blast circuit-breakers suitable for voltages from 132 to 650 kV and possibly higher, with current ratings of 2000 and 4000 A, short-circuit ratings up to 50 or 60 kA, and very short total break times. An order for the first 400-kV switchgear of this type has already been received from the Central Electricity Generating Board for installation at the West Burton Power Station, and covers thirteen 35,000-MVA air-blast circuit-breakers, eight of which will be rated at 4000 A and five at 2000 A, together with the power-operated isolators and other apparatus necessary to form a complete duplicate busbar switching station.

The new breaker, designated the "frame 'r' " breaker, is manufactured on a unit basis. Each unit is fully works-tested separately, thereby avoiding the necessity of assembling the complete breaker in the works. Various ratings are met by the use of multiples of a unit interrupter, connected in series horizontally and capable of extension to the highest voltages. The contacts are pressurized at full air pressure both in the open and closed positions, so that full operating pressure is available at the contacts and there is no pressure drop or time delay in filling support insulators, such as occurs with breakers having blast valves located at the air receiver. Also, as the contacts are pressurized in the open position, the normal make-switch is dispensed with, minimizing air consumption and eliminating external moving parts which may be subjected to icing and other adverse weather conditions. Other features include a neat and clean appearance, the reduction of height to a minimum, easy accessibility of all parts for inspection and maintenance, and a greatly increased speed of opening, as the arcing contacts do not part until approximately half the travel has been completed.

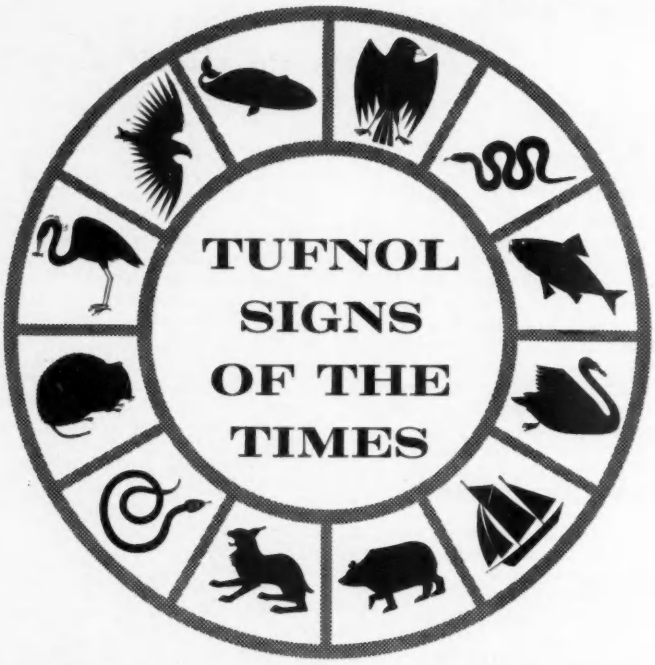
The interrupters can be arranged in a T formation (two interrupters per column), a Y formation (four interrupters per column), or a combination of both, i.e., a YT formation. Thus, a three-column breaker with six interrupters in a T formation is suitable for 275/330 kV, 15,000 MVA, and a two-column breaker with eight interrupters in a Y formation is suitable for 400 kV, 25,000 MVA. The illustration shows a ten-interrupter breaker made up of two four-interrupter units in a Y formation (one at each end), with a two-interrupter unit in a T formation in the middle. This YT formation is suitable for 400 kV, 35,000 MVA, or for 500 kV, 30,000 MVA. Other arrangements are, of course, feasible, and it will be appreciated that, for breakers with two or four interrupters per phase, all three poles can be accommodated on one air receiver.

The high-pressure air (300 psig) is contained within the support columns and interrupter porcelain within epoxy-resin-bonded glass tubes. The outer space between the tubes and porcelain is permanently held at a pressure of 2 psig. The actuating device is a small pneumatically operated spring trip mechanism of the type used successfully for many years in oil circuit-breakers. This mechanism is located in a cabinet attached to the main air receiver of one phase and operates control levers situated in a box on the centre casting of each pair of interrupters by means of epoxy glass-fibre rods located in the space between the porcelains and main epoxy-resin-bonded glass tubes. These rods are spring-loaded, so that there is no lost motion due to slack. To initiate a trip operation, the shunt trip coil is energized, thereby releasing the latch and, by means of the epoxy glass-fibre rods, the subsequent motion causes the master levers in the interrupter control boxes to depress the pilot trip valves, which in turn feed the blast valves. To close the breaker, the mechanism restores the rods to the latched position, thus causing the master levers to depress the closing valves in the interrupter control boxes.



The interrupters, which are built in pairs with one blast valve and control mechanism per pair of interrupters, consist of a cylindrical fixed main contact housing a spring-loaded arcing contact and a moving throat located in a second cylinder attached to the centre casting. Opening of the blast valve drains the air from the back of the operating pistons and the back of the moving throat, causing the latter to move inwards towards the centre of each interrupter pair. The main current-carrying contacts part, leaving the circuit made through the arcing contacts. The spring-loaded arcing contact is arrested at about half the travel distance of the moving throat, thus providing a high-speed break. The arc is drawn, transferred to the arcing tips, and extinguished by the flow of air through the nozzle.

Levers attached to the moving shaft operate a special toggle device which mechanically holds the contacts either closed or open and prevents contact movement in the event of an air leak. The same movement, transmitted by a lever, resets the master operating lever to the neutral position ready for closing, and allows the pilot valve and consequently the blast valve to close. The



Vole–sign of Tufnol

Those people born under the sign of the Vole burrow their way to the top of their profession to become chief purchasing officers, chief engineers, chief draughtsmen and chief designers. Vole men are specialists in their field of country and know exactly what they want. Vole men are perfectionists. They yearn for one material that combines the properties of many—a material that is light yet strong and hard wearing, resistant to corrosion and a good electrical insulator. They expect this ideal material to resist deterioration in storage, to machine easily with ordinary tools, and to be available in sheets, tubes, rods, angles and channels. Many Vole men have already ferreted out this remarkable material—"VOLE" brand Tufnol. They have also discovered that Tufnol is available in eleven other brands, each with pre-determined properties.

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whole of the interrupter space is then repressurized to full pressure, so that the breaker in the open position will withstand the full system voltage. When the closing valve is operated, it drains the space in front of the operating pistons to atmosphere, and the differential pressure causes the moving throats to close. Making is effected on the arcing contacts under full pressure, with negligible pre-arcing, and the spring-loaded arcing contact is then driven home, allowing the main current-carrying contacts to make. The levers then return the toggle device to its original position and reset the master lever in the neutral position ready for tripping, thus allowing the closing valve to close.

Immediately following each operation the control mechanism and contacts are ready for the next operation. The mechanism itself is of the quick-reset pattern, so that only the addition of an auto-reclose timing relay is necessary. Dead times down to 10 cycles or even less can be attained and, by means of the relay, any higher dead times can be used. Because of the inherent design features, arcing times are kept to the minimum, the breaker having a total break time of 0·05 sec maximum, i.e., 2½ cycles on a 50-cps basis. Performance on line dropping is extremely good, owing to the high pressure and fast break, and the breaker is restrike-free.

The breaker can be equipped with two types of resistor, i.e., heavy-duty and light-duty. Heavy-duty resistors are required for making the breaker suitable for interrupting short line faults where the short-circuit duty per interrupter is particularly high. The performance of the interrupter is so good that it is only for the more onerous short-circuit levels that these resistors are required, and even then it is not necessary to apply full critical damping of the line side transient, but only sufficient damping to bring the rate of rise of restriking voltage within the capability of the interrupters. Light-duty resistors can be employed in all other cases, their function being to ensure voltage division between interrupters when the breaker is breaking current and to damp out over-voltages when the breaker is switching low inductive currents. Both sizes of resistor require resistor interrupters, and these are automatically switched on operation of the last valve. Capacitors are fitted across the interrupters to ensure even voltage distribution in the open position and also to help the resistors in this duty when the breaker is opening the circuit.

High-Sensitivity Sucrose Detector

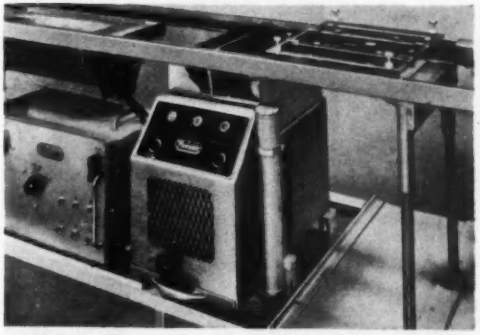
In the processing of sugar, severe corrosion of boilers as a result of sugar in the condensate has been a long-standing and serious problem, and can only be avoided by frequent sampling of the condensate returns and subsequent laboratory analysis. Unfortunately, laboratory tests have hitherto been sensitive to residuals down to about 10 ppm of sugar, so that any leakages of sugar below this value have had to be tolerated and the resulting acidity compensated by the addition of caustic soda to the boilers. It is now reported, however, that this problem has been solved by means of a new sucrose detector being produced by William Boby & Co. Ltd., of Rickmansworth, Herts. With this detector, the presence of as little as 2 ppm of sugar can be detected, and the equipment can be fitted with a relay to operate an alarm signal or alternatively a shut-down or dump valve.

The instrument, the principle of which is based on an analytical method developed by the British Sugar Corporation Ltd., involves the use of three simple reagents and an automatic built-in heater to boil the sample, the presence of sugar in the sample producing a colour change which is detected photo-electrically. Essentially, the method comprises boiling the sample at a low pH-value to hydrolyse sucrose to glucose and fructose, after which the pH-value is adjusted to 11 or above and the reagent triphenoltetrazolium chloride (TTC) is added. In the presence of reducing sugars, a strongly coloured precipitate called formazan is produced. These reactions are controlled by means of a multi-cam timing device which operates a number of valves and the electric heater in the proper sequence, and then switches in a photo-electric cell. The reactions, as well as the measurement, are carried out in a glass tube, the complete detector comprising two small cabinets, one measuring 13 × 13 × 10 in., and the other 10 × 10 × 8 in.

In operation, a measured sample of the water to be tested is introduced into the reaction tube, and a measured amount of acid from a stock tank is added. The electric heater then brings the acidified sample to the boil for a period sufficiently long to complete the hydrolysis, after which a measured quantity of caustic soda solution, also from a stock tank, is added to correct the pH-value, followed by a measured amount of TTC. Boiling continues up to this point, in order to mix the reagents and promote the reaction. The heater is then switched off, stopping ebullition, and the photo-electric cell takes a measurement across the glass tube, the signal from the cell being amplified and, if it falls short of a preset value, operating the alarm or other circuit. After measurement has been completed, the sample is drained out and a new cycle commences.

Automatic Fluxing Machine for Printed-Circuit Boards

The new "Flowfluxer" automatic fluxing machine announced by the Flowsolder Division of Fry's Metal Foundries Ltd., of Mitcham Junction, Surrey, has been developed specifically to speed up the fluxing process on production lines handling printed-circuit boards or panels. A special feature is that the boards move along a straight path, simplifying transfer-mechanism design and avoiding any hesitation, deviation, or break in production flow. After assembly, the panels pass through a smooth wave of flux, ensuring complete coverage and excellent joint penetration. There is no flux on the top side of the board, and flux brushing and flat dipping are eliminated, saving time and cutting wastage.



The machine, which is of compact design and is easy to operate, essentially comprises a stainless-steel storage tank of about 2 gallons capacity and measuring 12 × 9 × 16 in.

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deep. From the tank, the flux is drawn by a stainless-steel pump, with a specially designed impeller of 3 in. diameter, through stainless-steel tubes to a stainless-steel nozzle inside the tank. The pump, driven by a ¼-hp electric motor, delivers approximately 12 gpm at the nozzle aperture in the form of a smooth domed wave, whose height can be adjusted very accurately by means of a butterfly valve operated by a worm-gear mechanism. The design of the machine is such that cleaning can be effected very easily, and the necessary controls are simple and conveniently grouped on a control panel. An easily accessible drain tap is provided at the back of the machine to facilitate emptying, and a drip tray is incorporated to guard against accidental spillage from the tank. To ensure that clean flux is delivered from the nozzle, a removable filter is fitted to the tank outlet and a permanent filter to the nozzle. In addition, a nylon wiper is located alongside the nozzle to prevent dripping of excess flux.

When the fluxing machine is used in conjunction with the Fry "Flowsolder" automatic soldering machine, which works on the same principle, a completely automatic production line for soldered printed-circuit boards is produced. In this case, the panels, after passing through the fluxing machine, are preheated over infra-red elements and are carried by an automatic transfer mechanism to the soldering machine, where they are automatically soldered by a continuous wave of hot, clean solder. The illustration shows the automatic fluxing machine in a demonstration production line, with a printed-circuit board in its carrier ready to pass through the flux over infra-red driers and then through the soldering machine. It should be noted, however, that the fluxing machine can, if desired, be installed in any soldering production line. Furthermore, its use is not exclusively limited to fluxing operations, as its tank design is such that it can also be used satisfactorily for preservation or other suitable applications.

Coil-Spring Terminal Connectors for Telephone Wires

A new type of connector has been developed by the Bell Telephone Laboratories, of New York, and is now being produced by the Western Electric Company for use by local Bell Telephone companies. The connector, which is intended for connecting plastic-insulated small-gauge wires to terminal posts, is expected to supplant the conventional method of connecting telephone wires to terminals by means of an arrangement embodying a binding-post and nut, and will be used in terminal boxes such as those mounted on telephone poles and in the basements of buildings. With the new type of connector, wires can be connected rapidly, without the preliminary requirement of stripping the insulation. In addition, the wires can be connected and disconnected without disturbing other wires connected to the same post. By contrast, when a binding-post and nut are used, all wires on the post must often be disconnected and then reconnected to service one wire.

The new connector has the appearance of a coil spring, but has the important difference that, instead of using round or oval spring wire, the wire is square-shaped. When the insulated wire is looped once around the spring and pulled tight, the wire is forced between two turns of the coil, the sharp square ends of the connector biting through the plastic insulation and making with the wire multiple contacts which are both electrically stable and vibration-proof. Other wires can be forced into other turns of the coil spring, and any wire can be removed without disturbing other wires. The connector is made of tin-plated phosphor-bronze wire, about $\frac{1}{16}$ in. square, wound into a coil of about $\frac{3}{8}$ in. outside diameter. A brass post through the centre of the coil supports it and attaches it to the terminal block. The present design of terminal block has two rows of coil-spring connectors and will be used initially as multiple terminals for offices and apartments. Tests on these connectors in reactive environments, e.g., hydrogen sulphide, and under changing temperature conditions show that the wires themselves will fail before the electrical connections are affected.

Twin-Cylinder, Water-Cooled Outboard Motors

A new range of five outboard motors, suitable for a wide variety of craft, is announced by the Perkins Group and will be marketed throughout the world in 1962. Rated respectively at 4½, 6½, 18, 30, and 40 hp, all these water-cooled motors have well-silenced two-cylinder, two-stroke power heads and are of attractive streamlined design. All models feature the use of a separate fuel tank, the respective capacities being about 2¾ gal for the 4½- and 6½-hp motors, and 5½ gal for the 18-, 30-, and 40-hp motors. The use of a fuel tank not attached to the engine, but carried separately in the boat, is unusual in the case of smaller motors, such as the 4½-hp motor, and has the advantages of giving the motor a far greater range than a small built-in tank, as well as doing away with the necessity for carrying petrol cans and making the motor easier to carry. All models use a petrol/oil mixture, ranging from 16 : 1 for the 4½- and 6½-hp motors to 21 : 1 for the 18-hp motor and 24 : 1 for the 30- and 40-hp motors.

The Perkins 6·5 motor, rated at 6½ hp at 4500 rpm, is a greatly improved and up-rated version of the current Perkins 6-hp model, while the Perkins 18 motor, rated at 18 hp at 4500 rpm, has been developed from the present 16-hp motor and is available with electric or with manual starting. The Perkins 4·5 motor, rated at 4½ hp at 4000 rpm, is an entirely new design, with an extremely

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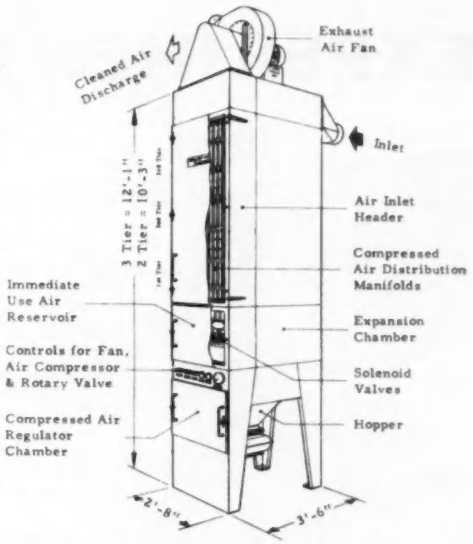
neat appearance. Its oval top shroud, like the 6½-hp motor, contains a built-in cord-type manual starter with automatic rewind, four-port reed-type intake valves, and a semi-weedless propeller with shear-pin protection. A special feature of this motor is that it can be rotated through 360 deg., giving great manoeuvrability and obviating the need for a reverse gear, as distinct from the other motors in the range, which have a forward, neutral, and reverse gearbox.

The Perkins 40 motor, rated at 40 hp at 4500 rpm, is of special interest, by virtue of its "sealed-off" power head suspended on rubber mountings. This feature, combined with an improved downward-directed silencing system, has conferred on the engine a vibration-free quality and exceptional freedom from noise. The throttle and gear-shift remote-control system are concealed beneath a one-piece fibre-glass top shroud, which can be removed instantly by operating a single finger-pressure catch. As with all motors in the range, an under-water exhaust is provided, and cooling is effected by forced circulation from a submerged water pump with a neoprene impeller, tell-tale holes being fitted at the rear for a visual check of circulation. The motor, like the Perkins 30, which is rated at 30 hp at 4500 rpm and is of basically similar design, is fitted with poppet-type intake valves and is available with either electric starting and emergency manual starting, or manual starting with automatic rewind. The weight of the 40-hp motor is 130 lb (manual starting) or 137 lb (electric starting), as compared with about 125 or 132 lb for the Perkins 30 motor, 85 or 95 lb for the Perkins 18 motor, 60 lb for the Perkins 6·5 motor, and 40 lb for the Perkins 4·5 motor.

Automatic Fabric Dust-Collector for Continuous Filtration

The new "Dalamatic" automatic fabric filter, announced by Dallow Lambert & Co. Ltd., of Thurmaston, Leicester, incorporates an integrated system of standard filter units in such a way that it is possible to assemble installations capable of handling air volumes of the order of 100,000 cfm (or more, if required), coupled with a filtration efficiency of virtually 100%, low energy requirements and maintenance costs, uniform air throughput, reliable operation, and compactness. Although the equipment uses limited quantities of compressed air as a cleaning medium, it embodies the fundamental dynamic air-flow characteristics generally associated with some blow-ring types of filters, but has the additional advantage of having no mechanical moving parts.

In its simple form, the unit can consist of assemblies of one, two, or three tiers, mounted on a hopper, silo pressure vessel, or conveyor to suit individual applications, a diagrammatic view of a three-tier, hopper-mounted assembly being illustrated. Each tier contains nine filter elements with a fabric area of 60 sq ft, i.e., 180 sq ft for the three-tier assembly shown. The filter elements consist of pad-type sleeves fitting over a specially designed matrix and header and can be constructed in a wide variety of natural or synthetic, woven or non-woven materials. The filter elements also act as flow straighteners and exert a significant influence on air-flow stability within the filter. The method of assembly used permits pad removal and inspection from the clean side of the filter, with practically none of the contamination normally associated with such a procedure. The filtration velocities obtained are substantially greater than those

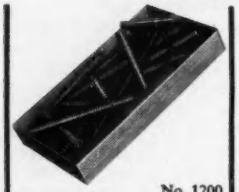


experienced with filters of orthodox design. Thus, a single three-tier assembly has an average continuously rated gas throughput of about 2000 cfm. For higher throughputs, multi-assemblies can be built up in a side-by-side or back-to-back arrangement, or a combination of both.

In operation, contaminated air is entrained into the filter above the level of the elements, passes downwards between them, and is filtered into a common outlet header running the height of the filter. Dust initially retained on the filtering medium is removed to the hopper below the filter and is eventually discharged by means of a rotary seal or by other conventional methods. In applications involving a heavy dust or product burden, a primary separator is integrated within the filter hopper, only the fines being circulated through the filter, so as to avoid any tendency to fabric abrasion becoming a significant factor.

The control of pressure drop caused by the deposition of collected dust on the filter medium is obtained by subjecting each vertical row of filtering elements to a predetermined cleaning cycle. Specially designed nozzles leading from high-pressure air-distribution lines extending over the element outlets deliver abrupt blasts of high-pressure air into the elements in a controlled sequence. As a result, there is a momentary reversal of the flow of filter air and this, coupled with a measured shock wave to the fabric element, dislodges the deposited dust, which falls into the hopper below. This movement of dust is greatly assisted by the overall air-flow profiles obtained with the design of contaminated-air inlet used. The duration of compressed-air delivery is so limited that there is no appreciable diminution of the main air throughput. The control of compressed-air delivery is effected by solenoid valves activated by a variable electrical impulse controller, different frequencies being used to suit different dust characteristics. The controller is mounted in a dust-tight enclosure and incorporates a constant-speed micro-motor which drives a multi-cam assembly through a series of reduction gears, activating the solenoid valves in turn by the sequenced operation of micro-switches.

EXPERIMENTAL SPRINGS?



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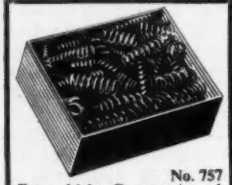

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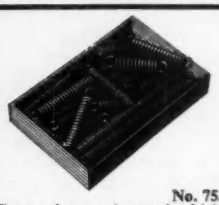

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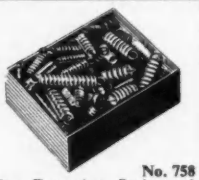

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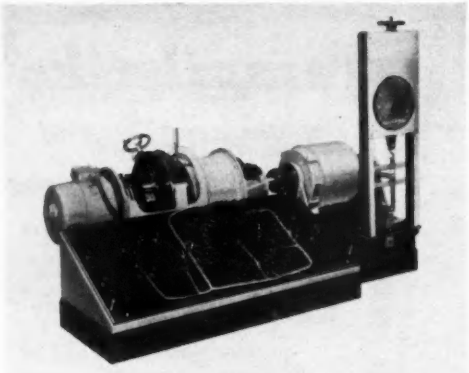
Generalized Educational Electrical Machine Set

Specially designed to teach the general approach to electro-mechanical energy conversion and to provide facilities for advanced research into electrical machines, the generalized electrical machine set developed by Mawdsley's Ltd., of Dursley, Glos., in collaboration with Dr. J. E. Brown of the University of Bristol and Mr. J. Kirkham of Oldham Technical College, makes it possible to demonstrate on one machine the complete range of operating modes of every type of a.c. and d.c. motor and generator. The set is suitable for use in laboratory courses at all educational levels, and is equally sstisfactory for illustrating either the new unified approach to electro-mechanical energy conversion or, at the most elementary level, the interrelationship between the performance characteristics of standard machine types.

The complete set consists of the generalized machine itself, a d.c. machine, and a torque-measuring unit, together with a built-in a.c. tacho-generator for measuring rotor speed. The generalized machine and the d.c. machine are coupled together and are mounted on a fabricated steel bedplate. The torque-measuring unit is completely separate, involving no electrical connections to the rotating shaft. The nominal rating of the generalized machine as a three-phase, four-pole induction motor is 4 bhp at 240 V, 50 cps, and 1400 rpm. The machine will, however, withstand severe overloads of the type regularly encountered in educational laboratories, and the insulation has been treated in such a way that a maximum winding temperature of 110°C can be tolerated. Provision is made for temperature measurements by means of a thermocouple and a mercury thermometer.



The stator of the generalized machine has a conventional four-pole a.c. winding in 48 slots, the ends of all 48 coils being brought out to 96 terminals symmetrically arranged in four concentric circles. In this way, the stator windings can be connected in either two-phase or three-phase form and, by suitable interconnection of the coils, for several different pole numbers. The position of slot No. 1 is clearly marked on the stator exterior for reference purposes, and a search coil is wound around a single stator tooth.

The rotor of the generalized machine has a four-pole lap winding in 36 slots, with a set of six symmetrical tappings to both sets. Special provision is made for connecting these tappings to four sliprings in various ways. A search coil around a single rotor tooth is permanently connected to two additional sliprings. The commutator, which has 144 segments, is equipped with two sets of brushgear and a pair of search brushes. One set of twelve brushes is similar to the racking brushgear of a Schrage motor, connections to all twelve brushes being brought out to the terminal panel. A second set of four brushes can be fixed in any desired position or driven around the commutator at speeds up to 750 rpm by means of a separate overhung brush-carriage motor. Connections to these brushes are brought out to the terminal panel via sliprings. The search brushes, with a variable span from 0 to 8 commutator segments, can be used to measure voltages between segments at all points around the periphery of the commutator. Scales are provided to permit measurement of the displacement of all brushes. In addition, provision has been made for shorting together all the commutator bars by means of a specially designed ring, producing a semi-squirrel-cage winding which responds to the various pole numbers that can be produced by the stator winding.

The d.c machine can be either a standard machine or the swinging-frame dynamometer, as used in several other Mawdsley educational machine sets. The frame of the dynamometer carries the field system and is mounted in pedestal trunnion bearings. A torque arm, with a simple reversing linkage, is connected at a radius of 0·5 metre to a spring balance calibrated in newtons. The movement of the swinging frame is restricted by stops above and below the torque arm.

The specially developed torque-measuring unit utilizes a radically new method of measuring the effects of the changes in permeability occurring in planes at angles of 45 deg. to the axis of a shaft subjected to torsional stress. This self-contained unit essentially consists of a main component and the associated excitation and measuring equipment. In appearance and construction, the main component is similar to the stator of a small electric motor with the shaft itself as the rotor. This stator is of split construction, so that it can easily be slipped around the shaft whose stress is to be measured.

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The new "Terrameter", announced by A.B.E.M. of Stockholm, Sweden, is a compact, lightweight, very-low-frequency a.c. instrument capable of achieving consistently accurate determinations of earth resistivity, even under the most varied and difficult geographic, climatic, and geological conditions. Using built-in standard dry batteries, the instrument is simple to operate and requires little or no maintenance. All components are fully tropicalized and are sealed against the ingress of moisture, dust, etc.

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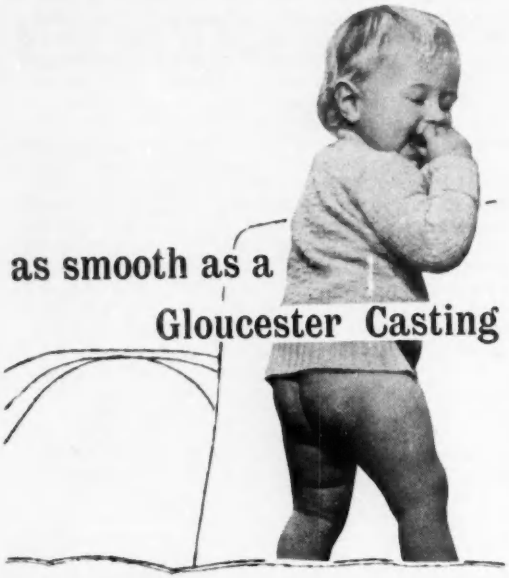

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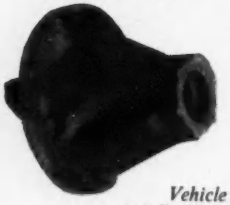
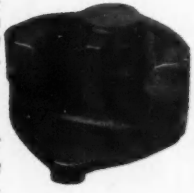


Right:
Spring mounting bracket in Malleable Iron Weight 8½ lbs.



Left:
Vehicle pinion housing in Malleable Iron. Weight 28 lbs.

A typical Gloucester Malleable specification.

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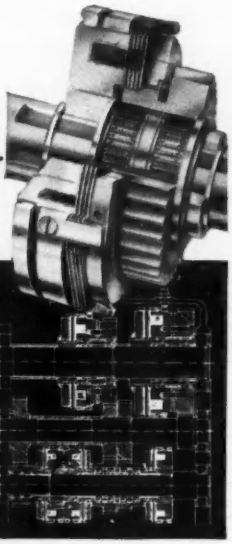

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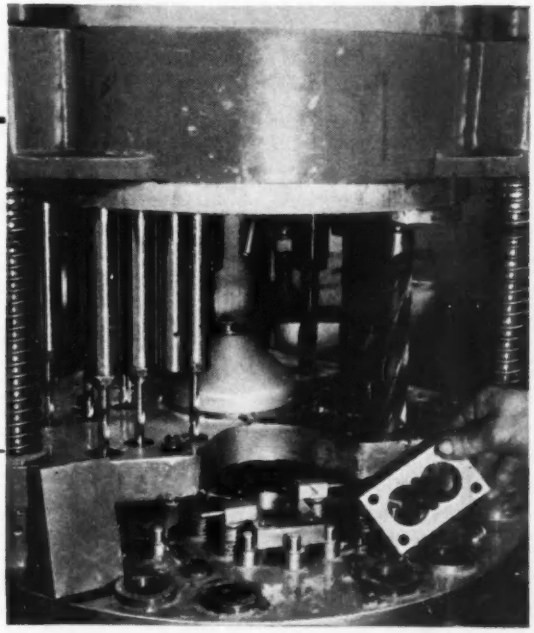

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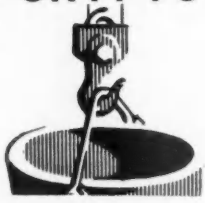

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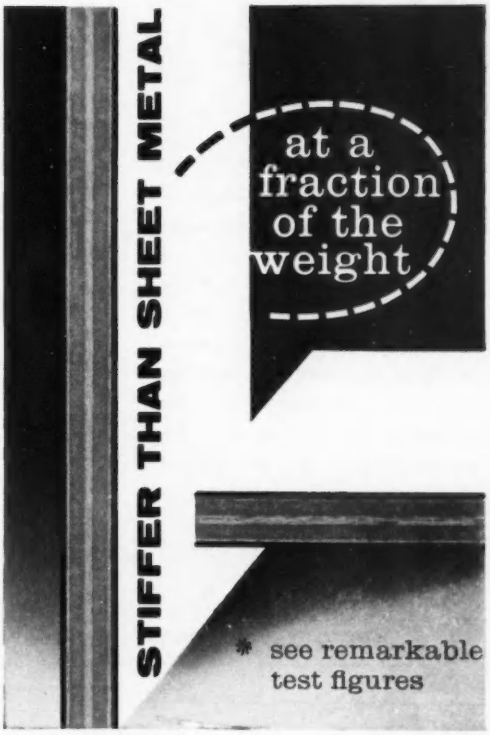

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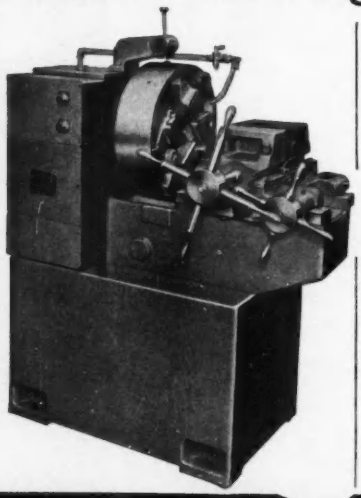

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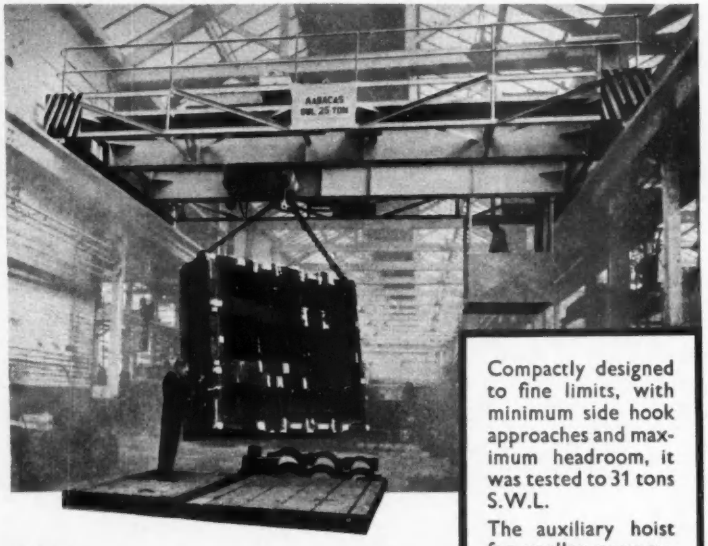

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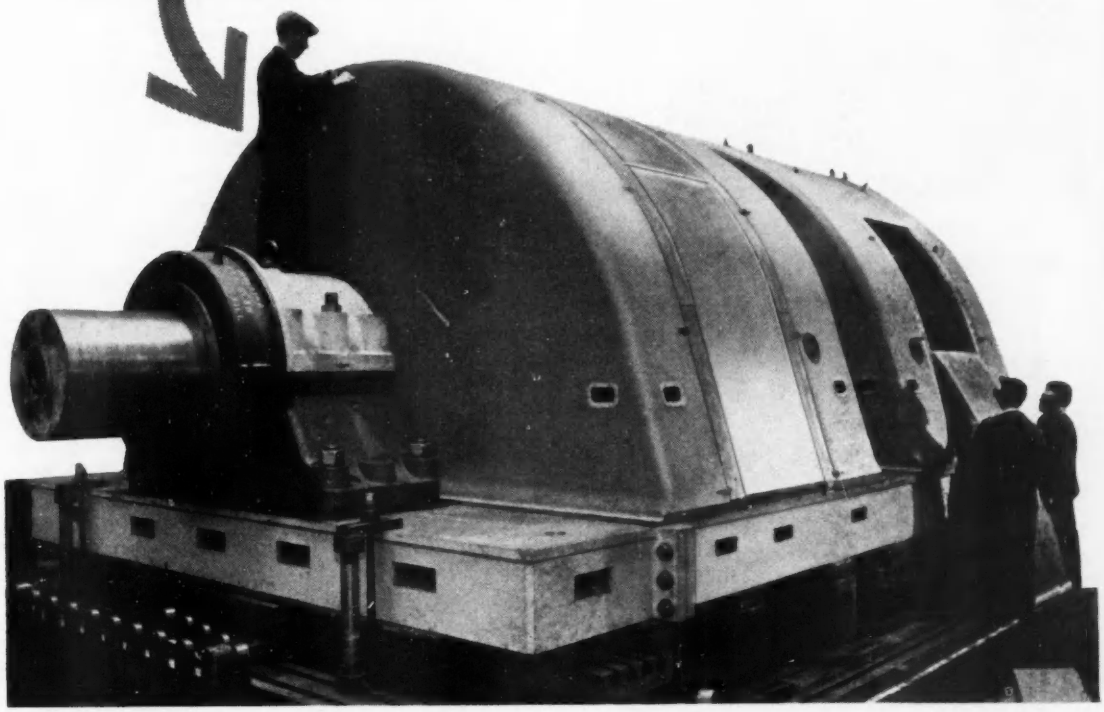

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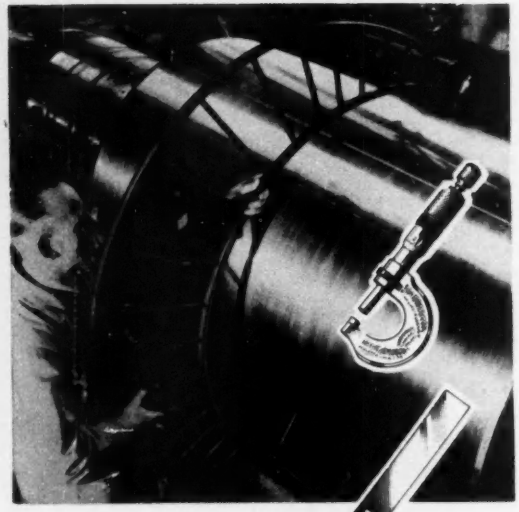

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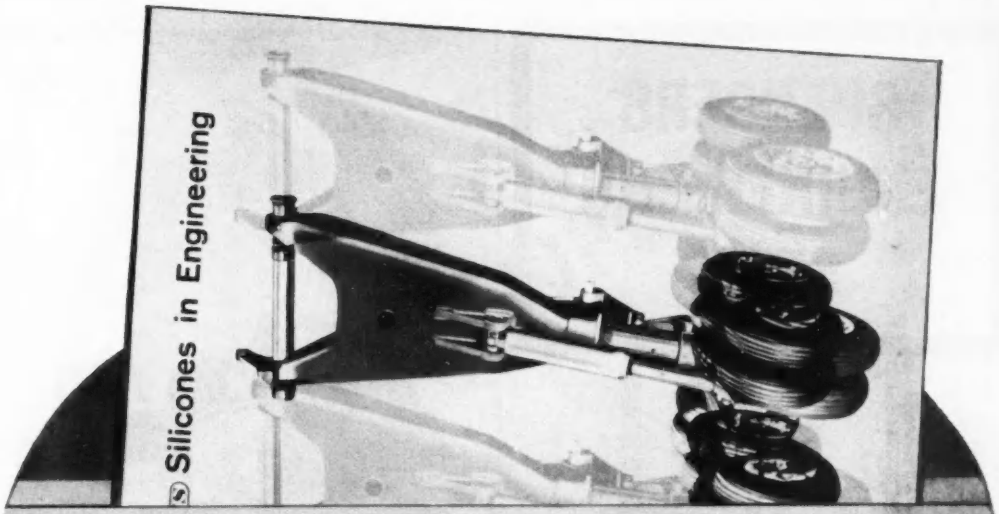

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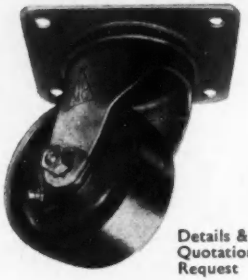

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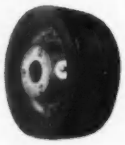

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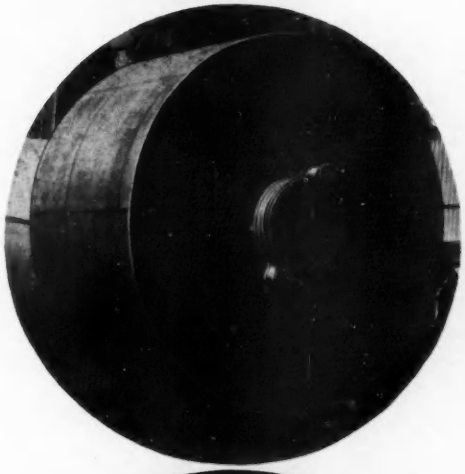

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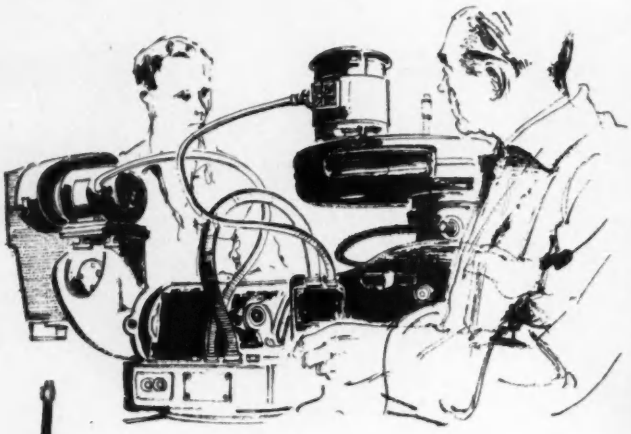

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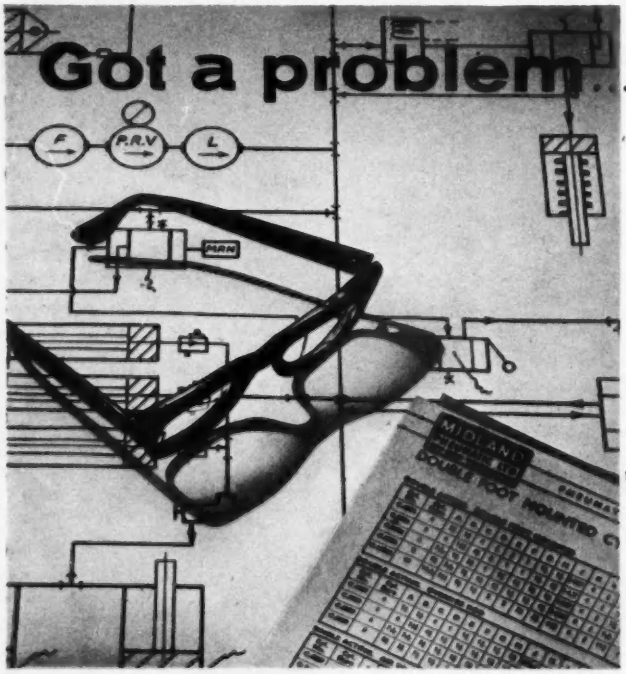

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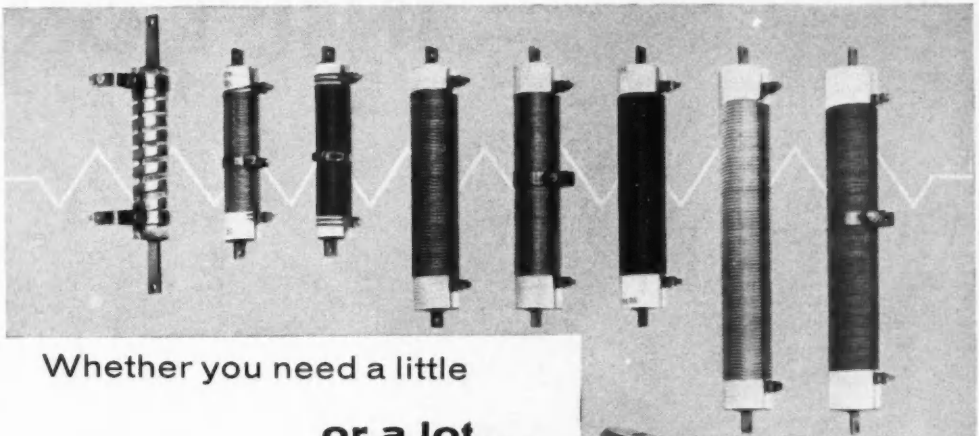

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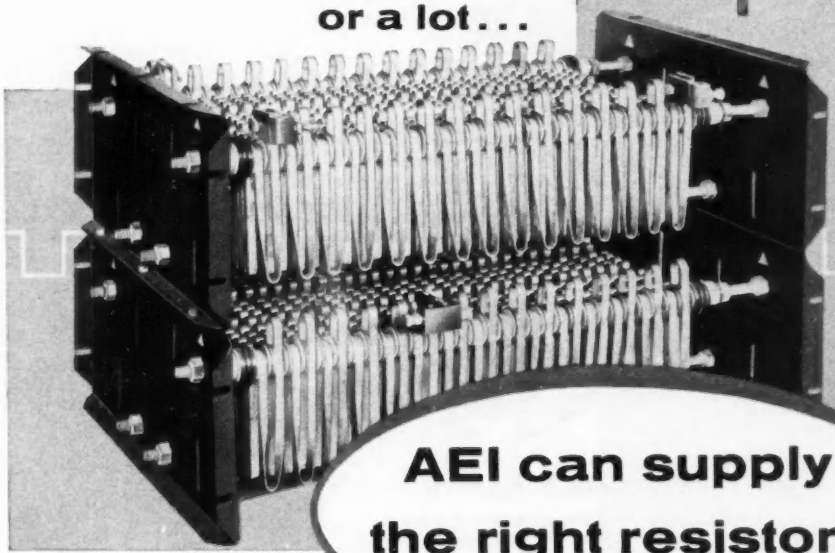

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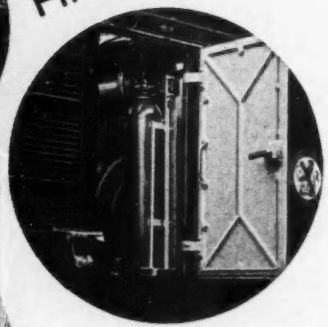
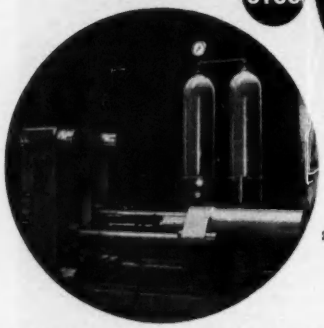


then the cylinder



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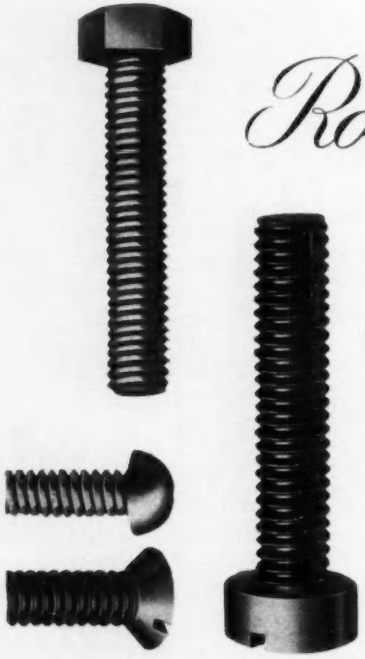

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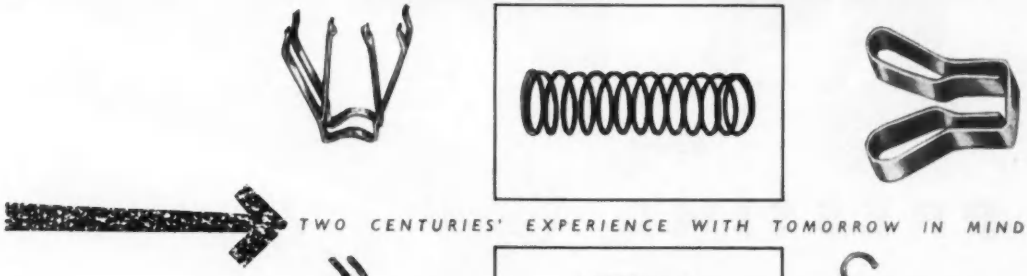

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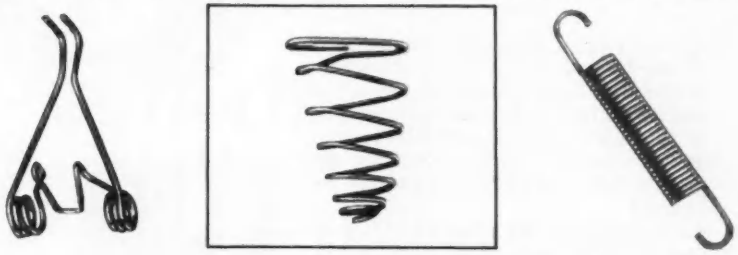

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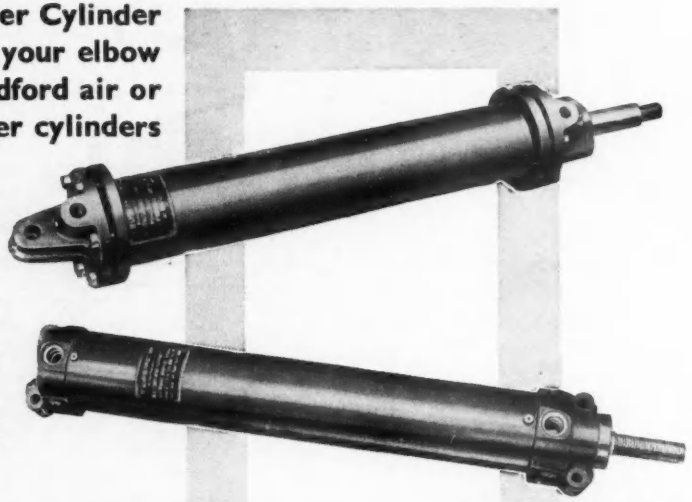

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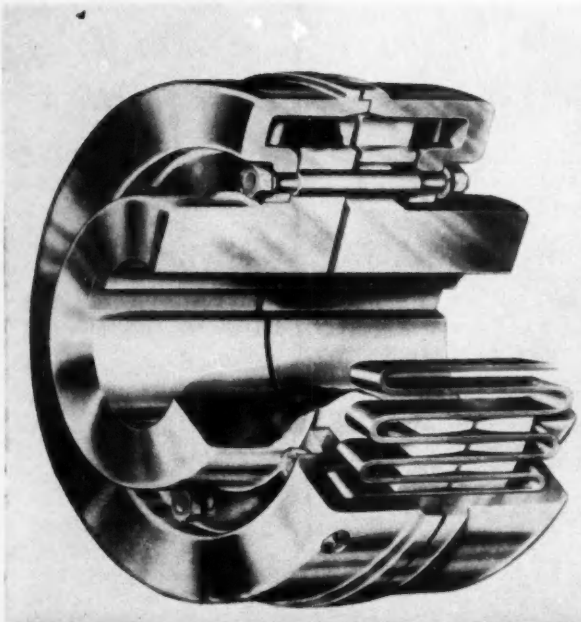

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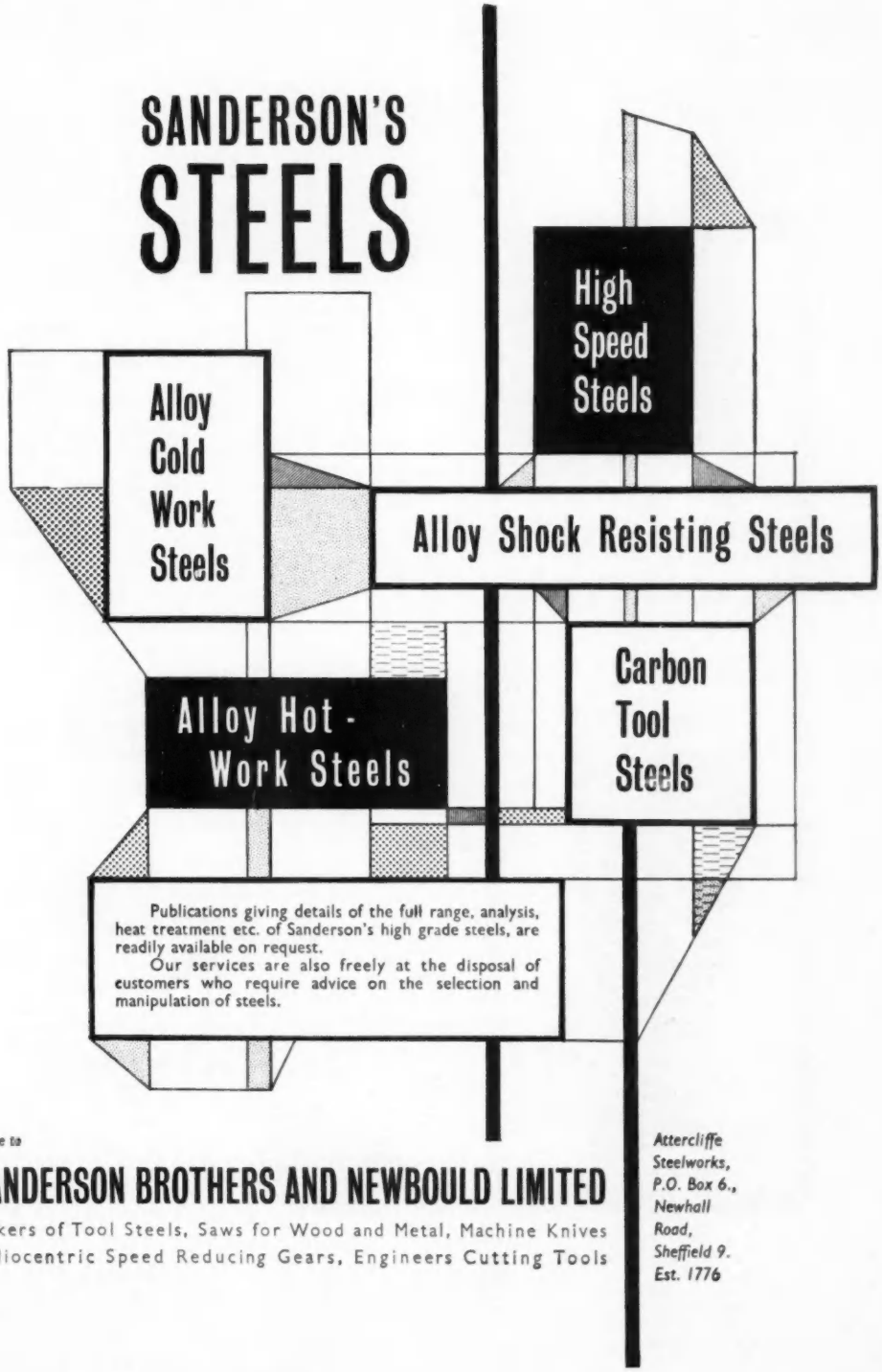

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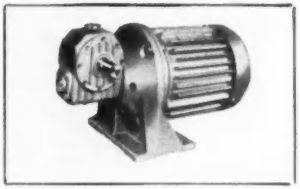

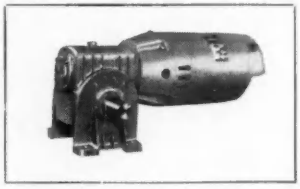

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CRC 89

Index of Current Advertisers and their Advertising Agents

Asbacas Engineering Co. Ltd. 136
Agency—Rowlinson Broughton Ltd.
Abbey Panel & Sheet Metal Co. Ltd. ..... —
Agency—Willington Adv. Ltd.
Acheson Colloids Ltd. ..... —
Agency—Norman Davis Ltd.
Ackworthie, John, Ltd. 109
Agency—Maurice G. Parker Ltd.
A.E.I.-Birlec Limited ..... —
Agency—Sandbrook, Metcalf & Co. Ltd.
A.E.I. Plastics (Aldridge) Ltd. 44
Agency—Taylor Advertising Ltd.
Allen, Edgar & Co. Ltd. 108
Agency—Rowlinson Broughton Ltd.
Allen, W. H., Sons & Co. Ltd. ..... —
Alexander Machinery (Kenametal) 112
Agency—Shaw & Underwood (Advertising Services) Ltd.
Alley Compressors Ltd. ..... Cover 3
Agency—Scottish Industrial Advertising
Alispeeds Ltd. ..... —
Agency—Hyde & Partners Ltd.
Alumilite & Alzak Ltd. 6
Agency—Beresford Bourke Ltd.
Anderton Springs Ltd. ..... —
Agency—Powney Parker Publicity Ltd.
Angus, George, & Co. Ltd. ..... —
Agency—Redheads Adv. Ltd.
Archdale, James, & Co. Ltd. ..... —
Armco Ltd. 39
Agency—Industrial Publicity Service Ltd.
Armstrong Stevens & Son Ltd. ..... —
Agency—Boswell, Barratt & Phillips Ltd.
Associated Electrical Industries Ltd. 145
Agency—T.G.A. Co. Ltd.
Atlas Plating Works Ltd. ..... —
Agency—White & Carter Ltd.
Automotive Engineering Ltd. ..... —
Agency—T. B. M. Advertising Ltd.
Automotive Products Co. Ltd. 38
Agency—H. Raymond Morgan
Avo Ltd. ..... —
Agency—National Publicity Co. Ltd.

B.I.P. Engineering Co. Ltd. ..... —
Agency—Central News Ltd.
B.R.C. Engineering Co. Ltd. 32
Agency—Murray Watson Ltd.
B.S.A Tools Ltd 106
Bailey, Sir W. H., & Co. Ltd. 20
Agency—T.G.A. Ltd.
Baker, John, & Bessemer Ltd. 148
Agency—J. Peers & Associates Ltd.
Balfour, Arthur, & Co. Ltd. ..... Cover 1
Agency—Charles Stanley & Partners Ltd.
Bellows Valvair Ltd. ..... —
Agency—Elliott Advertising Ltd.
Benson Bond Ltd. 113
Agency—Nigel Rainbow & Partners.
Benton & Stone Ltd. ..... —
Agency—Longleys & Hoffmann Ltd.
Berardi, Rino ..... —
Birfield Group ..... —
Birwelco Ltd. 158
Agency—Grosvenor Advertising Ltd.
Borg & Beck Co. Ltd. ..... —
Agency—H. Raymond Morgan
Brayshaw Tools Ltd. 110
Agency—Ineham Butterworth Ltd.
British Electric Resistance Co. Ltd. ..... —
Agency—John Collings & Partners Ltd.
British Federal Welder & Machine Co. Ltd. ..... —
Agency—Press and General Publicity Service Ltd.
British Manzel Oil Pump Co. ..... —
British Resin Products Ltd. ..... —
Agency—T. G. Scott & Son Ltd.
British Rolling Mills Ltd. ..... —
Agency—Maurice G. Parker Ltd.
Brookhirst Igranic Ltd. 54
Agency—Stanley D. Dickson
Broom & Wade Ltd. ..... —
Agency—Stephens Adv. Service Ltd.
Brotherhood, Peter, Ltd. 26
Agency—J. Peers & Assocs. Ltd.
Brown, Boveri & Co. Ltd. 28
Brown, David, Corporation (Sales) Ltd. 1
Agency—Oelrichs Advertising Ltd.
Brown Fintube (Great Britain) Ltd. ..... —
Agency—Grosvenor Advertising Ltd.
Buhler Brothers (England) Ltd. 62
Bull, John, Rubber Co. Ltd. 29
Agency—Frank Gayton Adv. Ltd.

Butterley Co. Ltd., The ..... —
Agency—Rowlinson-Broughton Ltd.

Camloc Fastener GMBH ..... —
Agency—Batten Barton, Durstine & Osborn GMBH
Cochran & Co. Annan, Ltd. 9
Agency—Allardyce Palmer Ltd.
Coppier, Fratelli ..... —
Carborundum Company Ltd., The ..... —
Carobronze Ltd. ..... —
Castrol Industrial Ltd 72
Agency—Dorland Adv. Ltd.
Chapman & Hall Ltd. ..... —
Chesterfield Tube Co. Ltd. 148
Agency—C. B. Casson Ltd.
Churchill Machine Tool Co. Ltd., The 22
Agency—Associated British Machine Tool Makers Ltd.
Clayton-Wright, Howard Ltd. ..... —
Agency—Don Earl Publicity Ltd.
Colt Ventilation Ltd. 50
Agency—Greenlys Ltd.
Compoflex Ltd. ..... —
Agency—T.G.A. Co. Ltd.
Cory Bros. & Co. Ltd. ..... Cover 3
Agency—Hyde & Partners Ltd.
Cossor Ltd., A. C. ..... —
Agency—Holmwood Advertising Ltd.
Coulthard, Wm., & Company Ltd. ..... —
Cradley Boiler Co. Ltd. 70
Agency—Riley Advertising Ltd.
Croda Ltd. ..... —
Agency—Farmer-Herbert Advertising Ltd.
Crofts (Engineers) Ltd. ..... —
Cronite Foundry Co. Ltd., The ..... Cover 2
Crowthorn Engineering Co. Ltd. 34
Agency—J. K. Clayton Advertising Ltd.

Dick, R. & J., Ltd. ..... —
Agency—Rex Publicity Ltd.
Doncaster, Daniel & Sons Ltd. 138
Agency—Rowlinson Broughton Ltd.
Dowty Seals Ltd. ..... —
Agency—Hamill Toms Ltd.

Eagle Pencil Co. 135
Agency—Saward Baker & Co. Ltd.
Electrical Development Association ..... —
Agency—Mather & Crowther Ltd.
Efco Furnaces Ltd. 120
Agency—Nigel Rainbow & Partners Ltd.
Electrical Power Engineering Co. (B'ham). Ltd. ..... —
Agency—Nicholls, Dorrity Advertising Ltd.
Elliott, B. (Machinery) Ltd. ..... —
Agency—Nigel Rainbow & Partners Ltd.
Elliott, E., Ltd. ..... —
Agency—Sterling Advertising Ltd.
Ellison, Geo. Ltd. ..... —
Agency—Crossley & Co. Ltd.
Empyrium Welding & Mfg. Co. Ltd. ..... —
Agency—Jack White & Assocs. Ltd.
Engineering Materials & Design Exhibition 40
Agency—F. John Roe Ltd.
English Electric Co. Ltd., The ..... —
Agency—Technical Advertising Service Ltd.
English Steel Tool Corporation 43
Agency—T.G.A. Ltd.
E.N.V. Engineering Co. Ltd. 47
Agency—Allardyce Palmer Ltd.
Evertaut Ltd. 8
Agency—Elliott Adv. Ltd.

Fabbrica Italiana Trapani Ideal ..... —
Fafnir Bearing Co. 146
Agency—H. Raymond Morgan
Faure Herman ..... —
Fel-Electric Ltd. ..... —
Agency—Oelrichs Advertising Ltd.
Fenner, J. H., & Co. Ltd. 46
Agency—Hyde & Partners Ltd.
Fibreglass Ltd. 137
Agency—Notley Advertising Ltd.

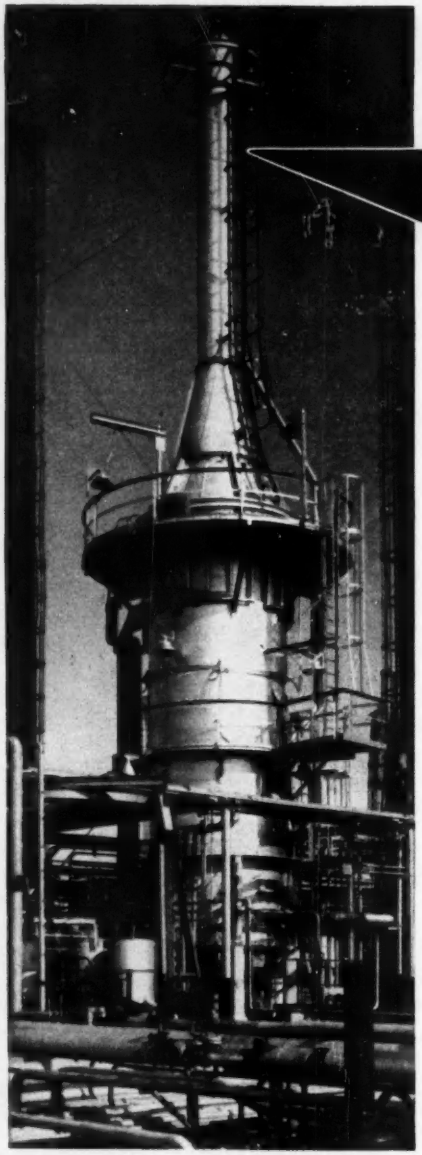
Firth-Derihon Stampings Ltd., The 36
Agency—Stanley D. Dickson
Firth, Thos. & John Brown Ltd. 111
Agency—Stanley D. Dickson
Ford Motor Co. Ltd. 25
Agency—London Press Exchange Ltd.
Forgings & Presswork Ltd. 74
Agency—Central News Ltd.
Fraser, Andrew & Co. Ltd. ..... —
Agency—J. Peers and Associates Ltd.

Goodyear Tyre & Rubber Co. (G.B.) Ltd. 114
Agency—Erwin Wasey, Ruthrauff & Ryan, Ltd.
Gear Grinding Co. Ltd. 27
Agency—Sandbrook, Metcalf & Co. Ltd.
General Electric Co. Ltd. ..... —
Agency—Greenlys Ltd.
Glacier Metal Co. Ltd. 16
Agency—Bean Adv. Ltd.
Gloucester Foundry Ltd. 130
Agency—Print for Industry Ltd.
Griffiths, Gilbart, Lloyd & Co. Ltd. ..... —
Agency—Nicholls, Dorrity Advertising Ltd.

H.M.C. Wheels Ltd. 142
Agency—Brandis Davis Agency Ltd.
Hackbridge & Hewittic Electric Co. Ltd. ..... —
Agency—Industrial Publicity Service Ltd.
Hadfields Ltd. 52
Hall & Hall Ltd. 31
Agency—J. Peers & Associates Ltd.
Hallmac Tools Ltd ..... 4 & 5
Agency—Jack White & Associates
Hancock & Co. (Engineers) Ltd. ..... —
Agency—Tibbenham Publicity Ltd.
Hardy Spicer Ltd. ..... —
Agency—Central News Ltd.
Heap, Joshua, & Co. Ltd. 136
Heenan & Froude Ltd. ..... —
Agency—Murray Watson Ltd.
Hermetic Rubber Co. Ltd. ..... —
Hoffmann, Mfg. Co. Ltd., The ..... —
Holcroft, Thomas & Sons. Ltd. 150
Agency—Severn Publicity Ltd.
Holden, Arthur, & Sons Ltd. ..... —
Agency—S. D. Toon & Heath Ltd.
Holroyd, John, & Co. Ltd. 134
Agency—C. R. Casson Ltd.
Holroyd, John, & Co. Ltd. 156
Agency—Ripley, Preston & Co. Ltd.
Hydraulics & Pneumatics Ltd. 147
Agency—S. C. Peacock (Birmingham) Ltd.

I.C.I. (Plastics) Ltd. 51
Agency—S. H. Benson
Imperial Aluminium Co. Ltd. 118
Agency—Service Advertising Co. Ltd.
Imperial Chemical Industries Ltd. ..... —
Agency—Everetts Ltd.
Impero Internazionale ..... —
Industrial Diamond Information Bureau 124
Agency—Intam Ltd.
Industrial Fan & Heater Co. Ltd. ..... —
Agency—Sinclair Advertising Ltd.
Intermit Limited ..... —
Agency—Sandbrook, Metcalf & Co. Ltd.
International Meehanite Co. Ltd., The 23
International Nickel Co. (Mond) Ltd. ..... —
Agency—T.G.A. Co. Ltd.
Ionic Plating Co. Ltd. 141
Agency—A. A. Black Ltd.
Isopad Ltd. ..... —
Agency—E. W. Barney Ltd.

Jacobs Mfg. Co. Ltd. ..... —
Agency—Crane Publicity Ltd.
Jenkins, Robert, & Co. Ltd. 143
Agency—W. Hopwood & Co. Ltd.
Johnson Foster, H., Ltd. 145
Agency—Pickersgill Publicity Service Ltd.



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Index *(continued)*

Kayser, Ellison, & Co. Ltd. 65
Keelavite Hydraulics Ltd. 69
Agency—Cogent Advertising Service Ltd.
Kendall & Gent Ltd. ..... —
Agency—Associated British Machine Tool Makers Ltd.
Kenilworth Mfg. Co. Ltd. ..... 130 & 140
Agency—Crossley & Co. Ltd
Kenyon, William & Sons 17
(Power Transmission) Ltd.
Agency—Bayard Publicity Ltd

Lancashire Dynamo & Crypto Ltd. 132
Agency—Technical Designs Ltd.
Lancers Machinery Ltd. ..... —
Agency—A.T.A. Advertising Ltd.
Lang Pneumatic Ltd. ..... —
Agency—J. Peers and Associates Ltd.
Laycock Engineering Ltd. 80
Agency—Central News Ltd.
Ley's Malleable Castings Co. Ltd ..... —
Agency—H. Raymond Morgan
Livet ..... —
Lodge Plugs Ltd. ..... —
Agency—Elliott Advertising Ltd.
London Shafting & Pulley Co. Ltd. ..... —
Agency—Nigel Rainbow & Partners Ltd.
Long Meadow Felt Co. Ltd ..... —
Agency—Severn Publicity Ltd.
Low Moor Alloy Steelworks Ltd ..... —
Agency—Powney Parker Publicity Services Ltd.

Mercedes-Benz 37
Agency—Heumann Werbegesellschaft G.m.b.H.
Mercer, Thos. (Air Gauges), Ltd. ..... —
Agency—Nigel Rainbow & Partners Ltd.
Metal Sections Ltd. 19
Agency—Sandbrook, Metcalf & Co. Ltd.
Metalock (Britain) Ltd. ..... Cover 2
Microtecnica ..... —
Midgley & Sutcliffe Ltd. 42
Agency—Monarch Adv. Co. Ltd.
Midland Industries Ltd. ..... —
Agency—A. A. Black Ltd.
Midland Pneumatic Ltd. 144
Agency—Sterling Advertising Ltd.
Midland Silicones Ltd. ..... 35, 96 & 139
Agency—Roles & Parker Ltd.
Mill Societa Generale delle Macchine ..... —
Mirrlees, Bickerton & Day Ltd. ..... —
Agency—Rowlinson-Broughton Ltd.
Mobil Oil Co. Ltd. 116
Agency—Masius & Fergusson Ltd.
Monks & Crane Ltd. 2
Agency—Sandbrook, Metcalf & Co. Ltd.
Mono Pumps Ltd. 142
Agency—Ripley, Preston & Co. Ltd.
Moore & Wright (Sheffield) Ltd. 138
Morgan Crucible Co. Ltd., The 160
Mountford, Fdk., Ltd. ..... —
Agency—S. D. Toon & Heath Ltd.

Neill, James, & Co. (Sheffield) Ltd. 15
Agency—J. K. Clayton Adv. Agency Ltd.
Newall Group Sales Ltd. 60
Agency—J. Peers and Associates Ltd.
Nitralloy Ltd. 12
Agency—Stanley D. Dickson
North British Locomotive Co. Ltd. ..... —
Agency—Scottish Industrial Advertising

Officine Meccaniche Fratelli Camurri di Nemesio-Rolo (R.E.) ..... —
Ormond Engineering Co. Ltd. 150
Agency—J. Manser Atkins & Co. Ltd.
Osborn, Samuel, & Co. Ltd. 64

P. R. Motors Ltd. ..... —
Agency—A. A. Black Ltd.

Parkinson Cowan Measurements 10
Agency—Roles & Parker Ltd.
Pergamon Press Ltd. ..... —
Perkins Gas Turbines Ltd. ..... —
Agency—Crane Adv. Ltd.
Pickering, R. Y., & Co. Ltd. 45
Agency—Barbour MacLaren Advertising Ltd.
Pitman, Sir Isaac, & Sons Ltd. 3
Pollard Bearings Ltd. 24
Agency—Hedley, Byrne & Co. Ltd.
Polypenco Ltd. ..... —
Agency—Anthony Handley Adv. Ltd.
Precision Gear Machines & Tools Ltd ..... —
Agency—Apex Adv. Ltd.
Pyrene Co. Ltd., The ..... —
Agency—Nelson Adv. Service Ltd.

Ransome & Marles Bearing Co. Ltd. 61
Agency—Ruddocks Advertising Agency
Renold Chains Ltd. ..... —
Reynolds Tube Co. Ltd. ..... —
Agency—Ripley, Preston & Co. Ltd.
Richards, Charles, & Sons Ltd. ..... —
Agency—Longleys & Hoffmann Ltd.
Richardsons Westgarth (Hartlepool) Ltd. ..... —
Agency—Notley Advertising Ltd.
Rockweld Ltd. ..... —
Agency—John Mitchell & Partners Ltd.
Rockwell Machine Tool Co. Ltd. 33
Agency—John Mitchell & Partners Ltd.
Rocol Ltd. 95
Agency—Nevin D. Hirst (Advertising) Ltd.
Rovetta Baldo ..... —
Royal Worcester Industrial Ceramics Ltd. 154
Agency—Nevin D. Hirst (Advertising) Ltd.
Royce Electric Furnaces Ltd ..... —
Agency—Nigel Rainbow & Partners
Ryder, Thos., & Son Ltd. 7
Agency—W. S. Crawford Ltd.

S.A.I.M.P. ..... —
Salter, Geo., & Co. Ltd. 151
Agency—Severn Publicity Ltd.
Sanderson, Bros., & Newbould Ltd. 155
Sandvik Swedish Steels Ltd. 107
Agency—Longleys & Hoffmann Ltd.
Saturn Industrial Gases Ltd. 53
Agency—Crossley & Co. Ltd.
Saunders-Roe Ltd. ..... —
Agency—Stanley D. Dickson
Self-Changing Gears Ltd. ..... —
Serck Radiators Ltd. 149
Agency—Longleys & Hoffmann Ltd.
Sheffield Twist Drill & Steel Co. Ltd. 41
Siemens—Schuckert (Great Britain) Ltd. 131
Agency—Smee's Advertising Ltd.
Slack & Parr Ltd. 131
Agency—Rex Publicity Ltd.
Sleeper C.E. Ltd. ..... —
Agency—Dryden Allen Ltd.
Slip Products & Engineering Co. Ltd. 13
Agency—Mark Fawdry Ltd.
Smith, C. & B., Ltd. 153
Agency—J.T.L. Advertising
Smith, S., & Sons (England) Ltd. 11
Agency—Masius & Fergusson Ltd.
Smith's Industrial Instruments Ltd. ..... —
Agency—Allardyce Palmer Ltd.
Socketex Ltd. 48
Agency—Shaw & Underwood (Advertising Services) Ltd.
Solex (Gauges) Ltd. ..... —
Agency—David Macauley Adv. Ltd.
Spencer Wire Co. Ltd. 140
Agency—Divers Advertising
Steel, J. M., & Co. Ltd. ..... 14 & 130
Agency—Reynell & Son Ltd.
Sterling Metals Ltd. 49
Agency—T. G. Scott & Son Ltd.
Stone, J., & Co. (Charlton) Ltd. ..... —
Agency—Holman Adv. Ltd.
Stone-Wallwork Ltd. 67
Agency—Holman Advertising Ltd.
Stubs, Peter, Ltd. ..... —
Agency—Rowlinson-Broughton Ltd.
Super Oil Seals & Gaskets Ltd. 68
Agency—A. A. Black Ltd.

Sykes, W. E., Ltd. 66
Agency—W. S. Crawford Ltd.

Teddington Aircraft Controls Ltd. 59
Agency—Stanley D. Dickson
Tempered Spring Co. Ltd. ..... —
Agency—Stowe & Bowden Ltd.
Terrapin Ltd. ..... 56 & 57
Agency—John Carr & Associates Ltd.
Terry, Herbert & Sons Ltd. 128
Agency—John Haddon & Co. Ltd.
Thorp, Thomas, & Co. Ltd. ..... —
Agency—J. Peers & Assoc. Ltd.
Titanium Metal and Alloys Ltd. 110
Agency—Alfred Bates & Son. Ltd.
Torrington Co. Ltd., The 55
Agency—Osborne Peacock Co. Ltd.
Tufnol Ltd. 122
Agency—Crossley & Co. Ltd.
Turner Bros., Asbestos Co. Ltd. ..... —
Agency—Crane-Wood Ltd.

Unbrako Socket Screw Co. Ltd. ..... —
Agency—Nicholls, Dorrity Adv. Ltd.
Unifinance (U.K.) Ltd. 71
Agency—Service Advertising Co. Ltd.
United States Metallic Packing Co. Ltd. 152
Agency—Wm. Furness Ltd.
Uni-Tubes Ltd. 144
Agency—Fredk. Aldridge Ltd.

Varagio-Strateline Gears Ltd. ..... —
Agency—Thomas G. Birtles Ltd.
Varley, F. M. C., Ltd. ..... —
Agency—J. Peers & Associates Ltd.
Venesta Plywood Ltd. 135
Agency—Taylor Advertising Ltd.
Vickers Armstrong (Engineers) Ltd. ..... Cover 4
Agency—T.G.A. Ltd.
Vokes Ltd. ..... —
Agency—Trowbridge, Pritchard & Co. Ltd.

Walker, Crosweller & Co. Ltd. 126
Agency—Beardmore Advertising Ltd.
Walpamur Co. Ltd., The 63
Agency—Osborne-Peacock Co. Ltd.
Ward, H. W., & Co. Ltd. ..... —
Agency—Associated British Machine Tool Makers Ltd.
Ward (Metal Details) Ltd. 152
Agency—Beardmore Advertising Ltd.
Weir, G. & J., Ltd. 30
Agency—Scottish Industrial Advertising
Wellman Bibby Co. Ltd., The 154
Wellworthy Ltd. ..... —
Agency Riggs Advertising Ltd.
Welsh Metal Industries Ltd. 133
Agency—Notley Advertising Ltd.
Westool Ltd. ..... —
Agency—Tibbenham Ltd.
Wharton Crane & Hoist Co. Ltd. ..... —
Agency—Henry Pybus Ltd.
White S.S. Dental Mfg. Co. (G.B.) Ltd. 58
Whitehouse Industries Ltd. ..... —
Agency—Hedley Byrne & Co. Ltd.
Wild-Barfield Electric Furnaces Ltd. 78
Agency—Crane Publicity Ltd.
Wolverhampton Diecasting Co. Ltd., The 76
Agency—Sterling Advertising Ltd.
Wragby Plastics Ltd. ..... —
Agency—Wilsmore & Tibbenham Ltd.

Young, Joseph & Sons Ltd. ..... —
Agency—Macdonald Adv. Ltd.

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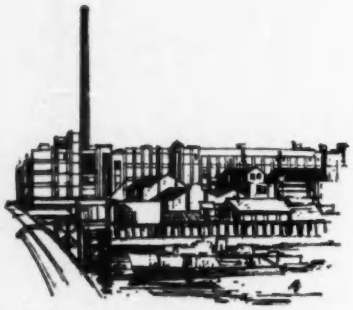

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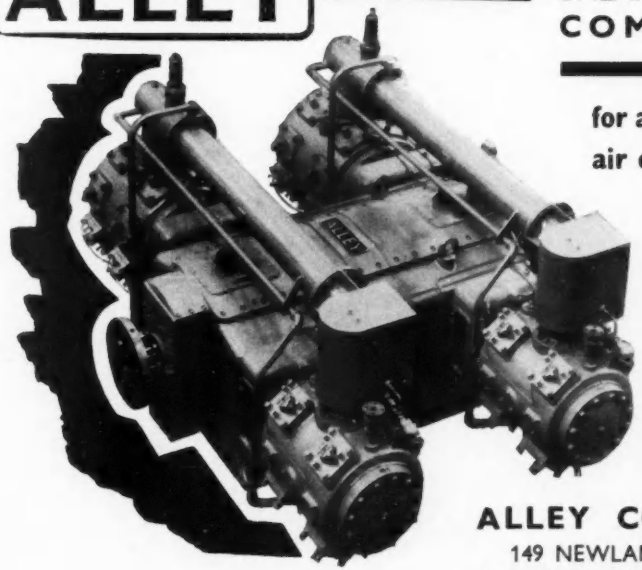

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